PHOTOGRAPHIC OPTICS

AND

COLOUR PHOTOGRAPHY

G. LINDSAY JOHNSON

LINDSAY JOHNSON'S SERIES OF HANDBOOKS

ON

APPLIED OPTICS

Edwin F. Northrup,
Oct - 1910.

PHOTOGRAPHIC OPTICS

AND

COLOUR PHOTOGRAPHY

PLATE I.

Portrait group from life ; reproduced by the Three-colour process, from an Autochrome photograph by the author ; time 5 seconds, in open air.

[*Facing Title-page.*

PHOTOGRAPHIC OPTICS

AND

COLOUR PHOTOGRAPHY

INCLUDING THE CAMERA, KINEMATOGRAPH, OPTICAL LANTERN, AND THE THEORY AND PRACTICE OF IMAGE FORMATION

BY

GEORGE LINDSAY JOHNSON

M.A., M.D., B.S., F.R.C.S.

[illegible] PHOTOGRAPHIC SOCIETY; [illegible] PHOTOGRAPHY
AND THEORETICAL AND [illegible] OPTICS TO THE [illegible], LONDON;
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WITH FOURTEEN FULL PAGE PLATES
FIVE OF THEM IN COLOUR
AND ONE HUNDRED AND SEVENTY ILLUSTRATIONS [illegible]

NEW YORK

D. VAN NOSTRAND COMPANY

PUBLISHERS AND BOOKSELLERS

23 MURRAY AND 27 WARREN STREETS

1909

PLATE I

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HON. FELLOW AMERICAN ACADEMY OF OPHTHALMOLOGY AND OTO-LARYNGOLOGY
HON. MEM. ROY. ACCADEMIA DI SCIENZE ED ARTI, MODENA
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To

DR. ALEXANDER GLEICHEN

REGIERUNGSRAT

THE EXTRAORDINARY CLEARNESS OF WHOSE WRITINGS HAS
MADE THE STUDY OF OPTICS A DELIGHT AND
RENDERED IMPERISHABLE SERVICE TO ALL STUDENTS OF SCIENCE
THIS LITTLE WORK ON PHOTOGRAPHIC OPTICS IS
DEDICATED WITH GRATITUDE AND ESTEEM
BY

THE AUTHOR

PREFACE

THE object of this work is partly in fulfilment of a pledge made over three years ago to a large number of opticians, that a work should be written on optical instruments to cover the ground of the Spectacle Makers' Company's Examination on that subject; but it is written in the hope that it will have a wider scope and play a much more useful part than merely to furnish material for examinees to read up.

It has long been the complaint of workers in various departments of science that no work exists dealing with the theory, construction, and practical working of the various classes of optical instruments. Numberless text-books on optics exist, but almost without exception they dismiss the subject of optical instruments in a few pages, as if they were of no importance at all. It is unfortunately the case, at least in England, that optics is either taught solely as an exercise in mathematics on the undulatory theory of light, or else so superficially as to be of little help to the student in other branches of science. In no work is it treated as a means to an end. So numerous have been the requests for a work of the kind referred to, that the author has made an attempt to meet it, and the series of text-books proposed is the result. It has been a far more arduous task than was anticipated, since in endeavouring to explain the various phenomena inseparably connected with the instruments, it was imperative to do so with the absolute minimum of mathematics, otherwise it would fail to meet the requirements of the very men for whom it was written. In embracing so large a subject the difficulty has been not so much to decide what to put in, as what to leave out. At the same time, it was found absolutely necessary to deal at some length with achromatism; with Fresnel's theories of wave motion, interference, and polarization; with the theory of lens systems and equivalent planes enunciated by Gauss; and lastly with the theories of diffraction as applied to the microscope by Abbe (and others)—since these form the four pillars on which the whole superstructure of practical optics rests.

No one is more conscious of the defects of this work, and especially of its poverty of explanation, than the author; and the reader must accept as the excuse for the immense amount of useful matter omitted, the imperative necessity of limiting the cost and size of the work as far as possible. For these reasons, only one instrument of each type is described, unless it introduces a new principle. At the same time, in order to prevent the work becoming too dry and technical, the author has here and there departed from the immediate scope of the work to introduce subjects of collateral interest, yet bearing on the main subject. The object kept in view throughout has not been to teach optics for its own sake, but to enable the student to grasp the fundamental principles of each instrument, to teach him how to work with it, and to test it, and to know the leading principles and facts of the science for which the instruments treated of are mainly used.

In this first handbook of the proposed series the author has given a brief description of the various forms of cameras and lenses at present in use, and discussed all the simple problems connected with

the lens and general optics of photography and the optical lantern, as far as is necessary for the student and optician, and he has illustrated each by abundant examples. For those who desire more advanced knowledge, the student is strongly recommended to the works of Gleichen, von Rohr, Cole, Silvanus Thompson, and Dennis Taylor, as well as Lord Rayleigh's collected papers and the numerous articles by Drs. Drysdale and Chalmers. The various processes connected with colour photography, and the physiological and physical problems dependent on them, have also been discussed. The author has also briefly touched on the theories of light action on the photographic plate, and given numerous rules for the student's guidance which he has amply proved in practice. He has, however, omitted all reference to the innumerable methods of printing and toning, and, indeed, to everything connected with art apart from science; and besides, these subjects will be found admirably treated in the classical works of Sir W. Abney, Prof. Eder, Chapman Jones, Child Bayley, Brothers, and Hasluck, and also in the "Barnet" book of Photography, and in the practical series of photographic handbooks edited by the Rev. F. C. Lambert.

The author acknowledges his indebtedness to Sir William Abney for kindly correcting the proof-sheets relating to the testing of shutters (Chapter III.) and to the sensitometer (Chapter IV.), and also for his permission to copy the drawings which illustrate his apparatus. He would also express his thanks to Dr. Drysdale for supplying the illustrations relating to speed measurement described in § 10; to Mr. Hopwood for the use of Figs. 18 to 23 inclusive, and for valuable information relating to living pictures; to Mr. A. E. Conradÿ for clearing up several points of doubt in connection with Chapter II., and for kindly revising several of the proof-sheets of that chapter; to Mr. Urban for much valuable information relating to the kinematograph, and for supplying several wood blocks (Figs. 28–33); to Mr. Sanger Shepherd and Mr. Welborne Piper for revising the articles on three-colour processes and on colour printing; to Mr. Edgar Senior for supplying the superb photograph of the Lippmann film section; to Messrs. Horwitz for the two clichés of the projectiles showing the condensed air waves; to Mr. Hinton, and to Mr. Sinclair for many helpful suggestions in relation to development. The author's thanks are also due to Mr. Sanders for several woodcuts, and also for the striking photograph of a gannet alighting on her nest; and to all the other numerous opticians who have generously placed their blocks at his disposal, and whose names will be found in the text; and to Mr. Lionel Laurance and Mr. H. O. Wood for revising the numerous calculations and formulæ to be found in the chapter on the lens, and for their great kindness in many ways.

The section on Telephoto Lenses had the advantage of revision by the late Mr. J. H. Dallmeyer shortly before his lamented death.

55, Queen Anne Street,
Cavendish Square, W.

ERRATA

Page vi, last line, *for* " J. H. Dallmeyer " *read* " T. R. Dallmeyer."

" 8, line 7, *for* " Houghton & Sons " *read* " Houghtons, Ltd."

" 14, line 14, *for* " 54 × 107 " *read* " 45 × 107 " mm.

" 14, line 17, *for* " $6\frac{1}{4} \times 3\frac{1}{8}$ " *read* " $6\frac{3}{4} \times 3\frac{1}{4}$."

" 62, line 2, *for* " $F_1 - F_2 - d$ " *read* " $F_1 + F_2 - d$ " in both expressions.

" 63, line 6, *for* " Adon lens " *read* " above figure."

" 66, line 6, *should read* $e_1 = \frac{t}{\mu} = \frac{2}{1{,}5} = \frac{4}{3}$.

" 67, line 2, *should read* $e_2 = \frac{t}{\mu} = \frac{2}{1{,}5} = \frac{4}{3}$.

" 70, line 1, *add* " $\mu = 1{,}6;\ t = 1;\ r_3 = -r_4 = 2$."

" 70, line 13, *for* " F'_1 and $F'_2 - d$ " *read* " $F'_1 + F'_2 - d$."

" 76, last line, *for* " $f_1 - f$ " *read* " $f_2 - f_1$."

" 105, line 22, *for* " Astigmat " *read* " Stigmat."

" 126, line 25, *for* " astigmat " *read* " anastigmat."

" 187, lines 15 and 19, *for* " Thornton & Picard's " *read* " The Thornton-Pickard Co.'s." *

" 190, Fig. 145, *add* " Manufactured by Thornton-Pickard Co.* and sold by Watson."

" 190, line 29, *for* " Thornton Picard " *read* " Thornton-Pickard." *

" 199, line 4, *for* " MgO_4 " *read* " 4MgO."

" 207, last line, *for* " Burroughs, Wellcome & Watts " *read* " Burroughs Wellcome & Co."

" 233, line 4, *for* " orange " *read* " deep greenish blue."

" 240, line 20, *for* " jet black " *read* " greenish grey."

" 253, line 11, *for* " light " *read* " lines."

" 271, line 6, *for* " Anachromat " *read* " Anastigmat."

" 275, line 8, *for* " 3-in." *read* " 9-in."

" 285, Note to Table 10, *for* " Burroughs, Wellcome & Watts " *read* " Burroughs Wellcome & Co."

* See advertisement, page 324.

NOTE.—The Author will be indebted to any reader who will kindly point out to him any further errors he may find.

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PHOTOGRAPHIC OPTICS

AND

COLOUR PHOTOGRAPHY

INCLUDING THE CAMERA, KINEMATOGRAPH, OPTICAL LANTERN, AND THE THEORY AND PRACTICE OF IMAGE FORMATION

CHAPTER I

THE CAMERA

§ 1. **Pinhole Camera.**—1. The simplest form of camera consists of a light-tight box, having a minute aperture in the centre of its front. It is known as the pinhole camera. Usually an ordinary camera is used, a disc of thin ferrotype plate or other metal being substituted for the lens. The plate is perforated by several pinholes varying from $\frac{1}{20}$ to $\frac{1}{50}$ in. in diameter, which can be used successively by rotating the disc.[1] In order to get the best definition, the size of the hole must be chosen according to the distance of the plate from the aperture, and the distance and nature of the object to be photographed.

The rays which pass through the pinhole correspond to those which pass through the optical centre of the lens.

The image is therefore reversed, and can be formed in any plane, *e.g.* B″A″, B′A′, or BA (Fig. 1).

The smaller the aperture, the nearer the rays correspond to central rays, and the sharper will be the image. This holds true up to the point when the scale is turned by the diffraction set up. It is necessary, therefore, to have a different-sized pinhole for varying distances of object and length of camera, in order to get the best possible definition. Diffraction is due to the light waves being retarded, or bent, by striking the edge

[1] These discs made to fit any camera, and perforated with holes numbered in accordance with their size, can be obtained from Houghton, Fallowfield, Lizars, Adams, and other dealers.

of the pinhole. If the hole be very large compared to a wave length, the number of waves retarded is insignificant compared with the mass of unimpeded waves, and the diffraction will be unnoticeable; but if the hole be small compared with a wave length, the image which would otherwise be formed clearly and sharply, as if drawn with a pencil point equal in size to the pinhole, is impaired by the diffraction images. This is why a special hole must be found which will give the best results for a given distance of object and image.

The method of calculation is usually made on Lord Rayleigh's supposition that the limit of retardation should be taken

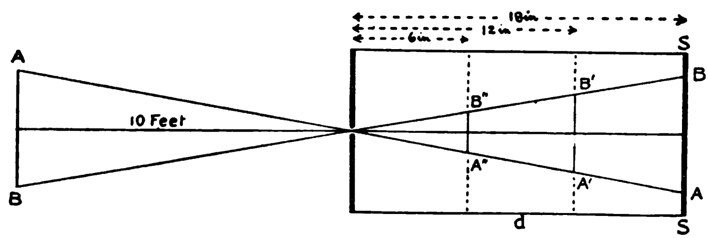


FIG. 1.—Diagram showing the path of rays in a pinhole camera. AB is the object; BA the image (reversed).

as $\frac{\lambda}{2}$; λ being the wave length for ordinary photographic blue-violet light.

Let $\frac{\lambda}{2}$ be the retardation (Fig. 2);

r the radius of pinhole aa';

and d the distance from the plate S;

also let aa' be perpendicular to a'P, the axis.

Then, if $$a'\mathrm{P} = d,\ a\mathrm{P} = d + \frac{\lambda}{2}$$

Since the angle aa'P is a right angle

$$r^2 + d^2 = \left(d + \frac{\lambda}{2}\right)^2. \quad \text{(Euclid I. 47.)}$$

Therefore $$r^2 = \left(d + \frac{\lambda}{2}\right)^2 - d^2 \quad \ldots\ldots \quad [1]$$

$$= d^2 + d\lambda + \frac{\lambda^2}{4} - d^2 = d\lambda$$

since $\frac{\lambda^2}{4}$, being very small, may be neglected.

Therefore $$r = \sqrt{d\lambda} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [2]$$

and $$d = \frac{r^2}{\lambda} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [3]$$

In other words, the distance of the pinhole from the plate equals square of the radius of the pinhole, divided by the length of a light wave ($0{,}59\mu$ to $0{,}4\mu$).

Example.—What is the correct diameter to make the pinhole for a camera 10 in. in length, the object being very remote compared with the length of the camera?

The distance of the plate from the pinhole is 10 in., and $\lambda = 0{,}000016$ in., or 0,0004 mm.

Therefore $r = \sqrt{0{,}000016 \times 10} = 0{,}013$ in.

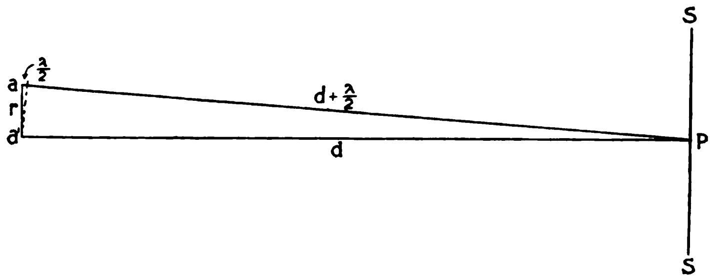


FIG. 2.—Diagram to illustrate the method of calculating the size of the aperture.

The correct diameter of the pinhole will therefore be

$$0{,}026 \text{ in.} = \tfrac{1}{40} \text{ in. (nearly)}$$

If the object be near compared with the length of the camera, another formula must be used. Let f_2 be distance of the pinhole from the plate, f_1 the distance of the object from the pinhole, and d the diameter of the pinhole. Then

$$d^2 = \frac{f_1 f_2}{f_1 + f_2} \times 0{,}81 \quad . \quad . \quad . \quad . \quad . \quad . \quad [4]$$

the latter being a constant, gives the value in millimetres, when f_1 and f_2 are expressed in metres or decimals of a metre.

Example.—The object is 2 metres distant, and the plate 0,25 metre (10 in.) from the pinhole: what will be the most effective aperture?

Here $f_1 = 2, f_2 = 0{,}25$,

Therefore $$d^2 = \frac{0{,}25 \times 2 \times 0{,}81}{0{,}25 + 2} = 0{,}18$$

and $$d = \sqrt{0{,}18} = 0{,}42 \text{ mm.}$$

If f_1 be very much larger than f_2, which it usually is, it may be omitted without any perceptible error, and the equation becomes simplified to

$$d = \sqrt{0{,}81 f_2}$$

Then in the above case

$$d = \sqrt{0{,}25 \times 0{,}81} \text{ or } 0{,}45 \text{ mm.}$$

We may therefore give the following rule :—

Multiply the distance between the screen and pinhole, expressed in decimals of a metre, by 0,81, *and the square root of the product will give the diameter of the pinhole in millimetres.*

The intensity of light is proportional to $\frac{d}{f_2}$ (f_2 being the distance of the screen from the hole), but it must be remembered, as D. J. Carnegie first pointed out,[1] that the thickness of the perforated plate always reduces its effectivity, so that the exposure must be increased in practice by about 30 per cent. This is more especially the case as the plate distance is diminished below 10 in.

The size of the picture is always the ratio between

$$\frac{\text{Distance of object from pinhole}}{\text{Distance of screen from pinhole}}$$

so that if the object is 20 ft. away, and the camera extension = 6 in., the image = $\frac{1}{40}$ of the object.

Pinhole pictures have the advantage of being invariably orthoscopic, but the exposure is enormously greater than with a lens. Compared with a portrait lens working at $\frac{F}{4}$, a pinhole made with a No. 5 needle ($\frac{1}{31}$ in. diameter), with the plate 15 in. distant, the exposure will be $\left(\frac{465}{4}\right)^2 = 116^2$, or about 13,400 times as long. Moreover, a pinhole does not give rise to point images, but to circular patches of light, or rather, diffraction rings, which are not sharply marked out, but fade away from the centre to the edge of the patch; the rate of fading depending on the distance of the screen and the diameter of the hole.

We have mentioned the pinhole camera first on account of its extreme simplicity, but in point of importance the following

[1] *British Journal of Photography*, June 22, 1906.

instrument stands first of all, since it was undoubtedly the pioneer of photography.

§ 2. **The Camera Obscura.**—This instrument was originally invented by Leonardo da Vinci, and also independently by Giambatista Porta of Naples. From the description he gives in his book on "Natural Magic," published in 1569, it is evident that it was not merely a pinhole camera, but the opening was fitted with a convex lens. "If," he says, "a small aperture is made in the shutter of a dark room, distinct images of all external objects will be depicted on the opposite wall in their true colours, and if a convex lens be fixed in the opening so that the images are received on a surface placed at the distance of its focal length, the picture will be rendered much more distinct."

If we make the body of a small camera constructed on these lines adjustable for the various movements of extension, elevation, and depression, and fit it to a bellows body, we have practically the camera of to-day.

§ 3. **Movements of the Camera Body.** — A modern camera having every movement, of which the "Sanderson" may be taken as a type, is adjustable in the following ways :—

1. The distance between the lens and the plate can be altered, either by extending the front forwards or the screen backwards. Stand cameras should have both movements. If it is wished to copy to the same size, the camera must be capable of extension to slightly more than twice the focal length of the lens, the slight additional extension being necessary to ensure correct focussing.

2. The swing-back allows of the plate being kept parallel to the object photographed, which is essential to prevent distortion of convergence, a defect which usually shows itself by the lower part of the picture being magnified more than the upper part, so that in the case of a building its sides appear to lean together. This is also of use when objects at various distances from the camera are required to be simultaneously in focus, without unduly stopping down the lens to get the necessary depth of focus.

3. There are two kinds of swing-backs, the one hinging from the centre, the other from the base. The former has the advantage that the middle distance, corresponding to the principal axis of the lens, remains in focus whichever way the back is tilted; in the latter the sky alone remains in focus

when the back is tilted, thus necessitating refocussing for the middle distance. As, however, the readjustment required is often very small, especially for objects in different planes, it may usually be neglected.

4. In addition to the vertical swing, the back may be capable of a lateral swing round a vertical axis, which is occasionally required when objects on one side of the medial line are on a nearer plane and can be brought into focus by a lateral extension of the opposite side of the camera. The lateral swing is also useful if the back is not reversible, since when the camera is placed on its side the lateral swing becomes a vertical one, but a *reversing* back is much the best form.

5. A rising front is necessary when photographing elevated

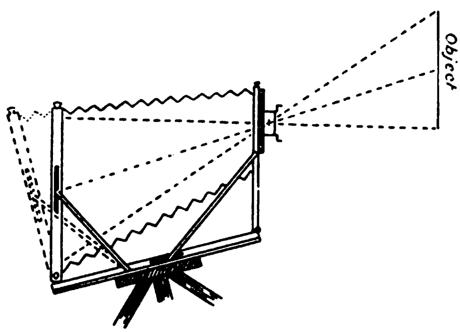


FIG. 3.—Diagram showing the use of the swing-back.

objects, such as churches, so as to obviate tilting of the camera and thereby causing distortion. The camera may, however, be tilted as much as you please, provided the screen is kept vertical. At the same time the front may be raised as well, and the image thrown up still more. Such an extreme displacement, however, can only be effected if the lens covers a much larger area than that of the focussing screen. A lowering front is similarly required for photographing the ground from an elevation, this being often necessary in mountain photography.

Fig. 3 shows how a camera fitted with a swing-back and rising-front can be adjusted to get the image of a lofty building on to the screen, while, at the same time, it preserves parallelism of the walls by keeping the screen perpendicular.

In this form of camera the front can also be swung to keep the axis of the lens horizontal, but this movement is of less importance than that of the back.

FIG. 4.—The Sanderson Camera. Type of a camera fitted with every movement required. It is a great favourite with amateurs.

6. A camera must be fitted with a bellows extension, so as to adapt it to take lenses of varying foci. It should be capable

FIG. 5.—Square Bellows Camera. Type of the ordinary camera used by most professionals. It combines all movements necessary, but the rising-front is limited to 1½ or 2 in. It is very serviceable and strongly made.

of extension to a little more than twice the focal length of the lens selected to cover the plate, so as to permit of photographs being taken life size.

7. As pictures are usually longer in one direction than the other, it is advantageous to have a reversible back, thus doing away with the necessity of unscrewing the camera and setting it up on the stand on one of its sides.

The "Sanderson" may be taken as the type of a camera which contains all these movements to perfection. It is made by Houghton & Sons (Fig. 4). Other simpler and very rigid forms are shown in Fig. 5 and Fig. 8. Some years ago this first-mentioned type was almost the only form of camera used by professionals and many amateurs for out-door work. It is still a great favourite with many. The accompanying sketch (Fig. 6) shows a favourite continental form of collapsible box

FIG. 6.—Ernemann's Focal Plane Camera.

camera. The focus is adjusted by means of a handle attached to the lens. A focal plane shutter is usually fitted in front of the plate, as in the Anschütz cameras of Goerz and Minimum Palmos of Zeiss, which are very similar to the above, but contain some extra fittings.

Fig. 7 shows a very useful and well-thought-out form of box camera (Perken & Son). It is a favourite with many amateurs. Newman & Guardia also make a somewhat similar camera, more expensive, but of exquisite workmanship, combining every requisite that the most fastidious amateur can desire.

§ 4. **Methods of obtaining an Upright Image.**—1. *By a mirror behind the focussing screen.*—A flat mirror backed with

felt in a light frame (to prevent breakage), and made the full size of the focussing screen, is a very useful addition. When inclined at 45° to the bottom of the screen, and covered over with a focussing cloth, the picture can be examined right way up, and the pictorial effect more easily arrived at. The only

FIG. 7.—Perken & Son's Adjustable Box Camera.

objection to its use is that it gives rise to lateral inversion. But this applies equally well to nearly all view-finders, and is rarely of any consequence except in process work. It can be

FIG. 8.—Sinclair's Una Camera, with hinge top for using a rising-front with very short focus lens.

readily made to hinge with its reflecting side next to the focussing glass, or be adapted to slide in a groove in the camera behind it when not in use. By a simple arrangement of bolt-hinges, I have contrived it so that it can be instantly detached

and made to hinge against either the long or the short side of the focussing glass.[1]

§ 5. **Reflex Camera.**—2. *By a moveable mirror hinged inside the camera body.*—A reflex camera, which is one in which the mirror is inclined at 45° inside the camera, and the ground glass is fitted horizontally into the upper part of the apparatus, effects the same result as the last method, the image being likewise laterally inverted. The mirror is backed by a blackened board which faces the sensitive plate. This board lies right against a flange (except during the exposure of the plate), so that no light can reach the latter. As the distance from the axis centre of the mirror to the centre of the focussing screen is exactly equal to the distance between the centre of the mirror and the plate, it is obvious that if the image is sharply focussed on the screen it will likewise be in focus on the plate when the mirror is raised (see Fig. 12). To make an exposure, the shutter (which is preferably a focal plane one, and made of black twill) is first drawn over the plate and adjusted to the desired speed. The object is then focussed on the screen. By pressing a release catch, the mirror swings up by means of a spring, and in the act of rising, releases the shutter-blind, which passes down over the plate. The exposure is effected by the horizontal aperture in the blind which traverses the entire length of the plate. The mechanism is so adjusted that the exposure is completed before the mirror strikes against the roof of the camera, which otherwise would cause a jar.

This form of camera is a great favourite with many amateurs, its chief objection being that it cannot be folded up like a bellows camera. Newman & Guardia, Ross, Watson, Shew, Marion, Beck, Sanders & Crowhurst (Fig. 9), Sinclair, Adams, and many others make a speciality of it. Sanders' instrument has an unusually long extension, and is extremely rigid. The image can be seen (full size) both on the top and in a line with the object. It is made for hard and rough work, and is not likely to get out of order.

Dallmeyer was the first to adapt the telephoto lens to the reflex camera, and his model is largely used by naturalists (Fig. 10). The long extension renders focussing difficult in

[1] Those who have not tried this plan will be agreeably surprised to find how the mirror assists in composing a picture, especially in portraiture. Messrs. Perken & Son carried out my ideas in a way that leaves nothing to be desired.

some of these cameras, and Dallmeyer fits to them a long rod fitted to a Hook's universal joint, which is exceedingly convenient.

Newman & Guardia supply a very convenient focussing

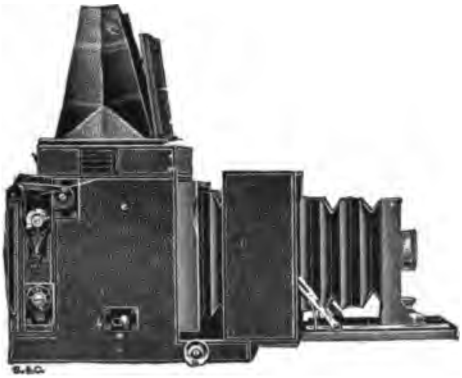


FIG. 9.—Birdland Reflex Camera, fitted for ordinary and telephoto work (Sanders & Crowhurst).

hood made of leather or cloth which can be pushed down out of the way into the body of the camera when not in use. On

FIG. 10.—Dallmeyer's Naturalist's Camera, fitted with portrait telephoto lens. The Hook's universal joint is not shown.

the top of the hood are a pair of eye-cups, which contain a pair of deep meniscus landscape lenses (described on p. 64). These are constructed on the pattern I have designed, and can be made of any focal length, positive or negative, to suit the

user's near point. They give a perfectly flat field, so that all parts of the image can be seen in focus. The camera has a revolving back so as to take pictures either horizontally or lengthways. The reflex cameras of Ross and Marion possess some admirable features. Since all the above-mentioned firms produce high-class reflex cameras having special features of their own, the photographer will do well to examine each separate type before making a purchase. With few exceptions all the best reflex cameras are made by Kershaw, of Leeds, who holds the patent for the roller-blind shutter used in all of them. He makes several different models of these cameras.

FIG. 11.—Kodak Reflex Camera.

The Tella Co. have just issued an exceedingly compact model, very light and rigid.

The Kodak Co. make a remarkably cheap and effective quarter-plate reflex camera (Fig. 11). Their Graflex camera (Fig. 12) merits attention. It possesses a second mirror, fitted with the top lid, which dispenses with the necessity of looking down into the camera. The mirror supplied to most reflex cameras consists of glass silvered on the surface. This is supposed to be better than an ordinary plain glass mirror silvered on the back, because it does away with the parallactic double image. In my opinion this is no objection, as, if the mirror be thin (*i.e.* not exceeding 2 mm.), the parallax is not noticeable in the ordinary mirror, and the brilliance of the image is unquestionably superior even when the front-faced mirror is new. The latest invention is the "Ernex Reflex" (Ernest Human), which is provided with a swing back, and the screen, mirror, and plate all move together. This enables the plate to be set vertically when the camera is tilted to photograph a lofty building.

§ 6. **By Means of a Double- or Twin-Lens Camera.**—This is more bulky and somewhat heavier than the reflex, and also more expensive, inasmuch as two identical lenses are necessary; but in some respects it is superior. One is able to observe the object, not only up to the time of releasing the shutter, but during exposure, as the upper camera is entirely

cut off from the lower one. Moreover (in some forms, at least), a double bellows body is possible, so that the camera can be folded up like an ordinary one, and is thus greatly reduced in thickness. Many photographers, however, prefer a *fixed* mirror attached to the upper camera, which then becomes a reflex camera, and the picture is thus seen erect, while the lower camera is being used like an ordinary one. This allows of the plate being uncovered throughout the focussing, by which no time is lost at the critical instant of exposure. For bird-life photography and animal photography generally, it is undoubtedly the best camera that can be employed, if the user can afford the extra expense, weight, and size of camera. Gambier Bolton employed this form of camera in taking his celebrated pictures of animal life. He used a whole-plate camera, I believe. Ross makes a speciality of this form of camera, which we have shown in Figs. 13A and 13B.

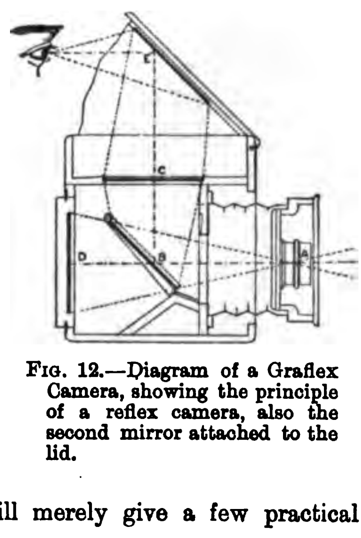


FIG. 12.—Diagram of a Graflex Camera, showing the principle of a reflex camera, also the second mirror attached to the lid.

§ 7. **Special Forms of Cameras.**—1. *Stereoscopic Cameras.* The principle involved in stereoscopic vision and the description of stereo cameras is given at length in our book devoted to the Stereoscope and Telemeter. We will merely give a few practical remarks.

First. The pictures may be any size you please if you employ a Wheatstone's mirror stereoscope, or the American sliding-bar pattern; but with the ordinary Brewster's stereoscope the size is necessarily limited.

Second. The stereoscope effect is directly proportional to the distance of the two lenses apart, with which the view is taken. In my opinion this width should never be *less* than $2\frac{1}{2}$ in. (64 mm.). For distant objects of still life, it is a good plan to screw a horizontal bar on the top of the tripod from 2 to 3 ft. in length, and marked with a scale each way from the centre. By fixing a clip underneath, the camera (which need not necessarily be a stereo one) can be slid along from one

end to the other, and exaggerated stereoscopic effect secured. This greatly enhances the relief, and is essential if you want to get stereo views of distant objects, since the eye cannot perceive plasticity beyond 250 or 300 yards. One foot is not a bit too wide apart to take stereo views in which the foreground is more than 300 yards away. This may even be increased for a very distant foreground with advantage. If you wish to study the effect of separation, you cannot do better than procure one of Zeiss' new stereo binoculars, or his telemeter binocular constructed on Helmholtz's model. These instruments will enable you to judge the effect of separation up to one metre or more.

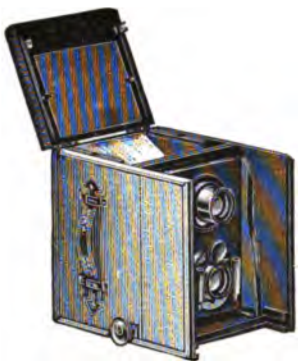


FIG. 13A.

FIG. 13B.

Fig. 13A.—Ross Twin-lens Camera. The folding focussing hood is pushed down inside the upper compartments. When raised it resembles the hood in Fig. 10. Fig. 13B shows the rotating back carrying the slide.

Stereoscopic cameras are very largely used in France, the favourite patterns being made entirely of metal. The usual sizes (double pictures) are 54 × 107 mm. ($1\frac{3}{4}'' \times 4\frac{1}{4}''$) and 60 × 130 mm. ($2\frac{3}{8}'' \times 5\frac{1}{8}''$). They are heavy and very rigid, but yet small enough to go into the pocket or an opera-glass case. In England larger sizes, 8 × 16 cm. ($6\frac{1}{4}'' \times 3\frac{1}{8}''$), are preferred, as the separate pictures form the regulation lantern size ($3'' \times 3''$), and can be used as such. Moreover, when a single lens is used, a useful panoramic picture, suitable for enlarging, or post-cards, can be secured. To obtain this, the central partition is shifted so that one of the lenses occupies the central position. The Stereoscopic Co., Zimmermann, Gaumont, Demaria, Lizars, Watson, and others, all make cameras of this

pattern. Butcher's stereo camera is a great favourite of the author's, being beautifully made, compact, and cheap.

Stereo positives on glass are far more effective than those mounted on cards, especially if backed by fine ground glass. They are made by direct contact with the negative, and the image is developed and fixed in the same way as the negative. Care must be taken to expose one at a time, in order to reverse the order of the pictures on making the transfer, otherwise the picture will come out laterally reversed. Of course the right-hand picture, as seen in nature, must also be the right-hand picture on the stereoscopic slide, or when looked at through the stereoscope. The image on the ground glass is not only upside down, but laterally reversed as well, and to correct this

FIG. 14.—A roll-film stereo and panoramic camera (Stereoscopic Co.).

latter fault it is necessary to do one of two things before making the positive. First, you may cut the double negative in half down the middle with a diamond, and then turn each over laterally, just as you turn the pages of a book, so that the left-hand side of each negative is now the right-hand side, although the relative positions of the right and left pictures remain unaltered. You then place them in this position, with the film side uppermost, quite squarely in the printing-frame, and place the plate (or paper) on the top in contact with it. Or, instead, you place the right picture of your undivided negative in contact with the left half of your plate, and, after exposing (with the other half of the plate screened from the light), you place the left picture of your negative in contact with the right half of

your plate. After developing, the picture will be seen with the right and left halves as they really were in nature, on turning the images right side up.

FIG. 15.—The "Block-Note" Stereoscopic Camera (Stereoscopic Co.).

§ 8. **The Panoramic Camera.**—This is a dark box, at the back of which is a frame, shaped to the arc of a circle whose radius equals the focal length of the lens employed.

The camera is made so that the lens can be rotated on a pivot, which lies in the plane of the second equivalent point (also called the optical centre, or Nodal point).

This pivot is the centre of the curved surface, on which a sensitive film is spread, its position being such that when the lens is rotated round a vertical axis passing through this point, the image of a distant object formed by the lens will remain stationary while the lens is rotated. *This is not the case if the lens be revolved round any other axis.* When the lens is rotated a continuous view—constituting a panorama—is projected on the sensitized film. By this means an angle of nearly 170° can be included. The film may be attached to any flexible support, such as gelatin or celluloid—in fact, any of the roller films of the proper size may be used. To prevent confusion of the image and the distortion and astigmatism produced by the oblique rays of the lens (which is rarely corrected for these aberrations), a narrow metal funnel, consisting of a vertical opening 4 in. long by 1 in. broad, is fixed to the back of the lens and rotates with it. The lens, therefore, can be made in a cheap form, since it is only required to include an angle of a few degrees, and only rays parallel to the principal axis are transmitted. The definition is excellent, even with otherwise very inferior

lenses. Stops varying between F/7 and F/32 are sometimes added. These are most useful, as it is much the best plan to keep the speed of rotation uniform, and to vary the exposure by altering the size of the stop.

The focus cannot be altered in any way. Owing to the image being projected on to a curved surface, the negative or print when flattened out causes a curvature in a horizontal plane in the foreground and middle distance, with the concavity directed towards the horizon. This is very noticeable in photographs of roads or railway lines parallel to the plane of the picture, but the curvature is not noticeable if they are mounted on a curved surface having the same radius as that in the camera.

In the "Al Vista" panoramic camera the speed can be regulated by affixing one of several double-vaned fans to the clockwork mechanism, the rotation of which, being resisted by the air, slows the movement of the lens. Personally, I prefer to keep to one speed, and vary the exposure by altering the stop.

FIG. 16.—Kodak Panoramic Camera.

Hinton has produced a "dual" panoramic camera, which will either take a picture 12 × 4 on a curved film, or, by a simple device, the film may be flattened out and the lens centrally fixed, by which an ordinary negative, 6 × 4, may be taken.

A panoramic camera of Italian manufacture is on the market, which is made to rotate, by means of clockwork, through a complete circle round a vertical axis, thus giving a picture which embraces the entire horizon. Messrs. Perken & Son stock it, I believe. It is quite useless for practical work except in connection with the kinematograph (see § 11).

Film Cameras.—These are the most popular of all cameras. They consist essentially of a compact box, having a hinged front, which opens and forms the baseboard for the bellows part. The Kodak Co. supply a large variety. They are made to carry a roller film, and may be adapted to hold cut films or plates as well. Beck makes an ingenious form,

the "Frena," which holds forty cut films arranged like a pack of cards. It is a great favourite with tourists. Shew makes a remarkably compact form.

Magazine Camera.—This is a box camera which contains a number of plates or films, each fitted with an opaque sheath. After exposure is made the plate (or film) in its sheath is rotated out of the way by means of a button on the outside of the camera. An elaborate form of this, termed "The Telephoto Cornex" (R. & J. Beck), takes both ordinary views and telephoto views at will. It holds twelve quarter plates.

§ 9. **Apparatus based on the Persistence of Vision and the Continued Perception of the Same Object.**—This is one of the most fascinating studies in physiological optics. It forms one of the earliest recorded optical phenomena. Even so far back as the Emperor Hadrian, Ptolemy, in his work on Optics, Vol. V. (A.D. 140), remarks: "If a sector of a disc be coloured in patches at various distances from the circumference, and then rapidly revolved, the sector will present the appearance of a series of coloured rings." Alhazen (A.D. 1100), Leonardo da Vinci, and Cardanus (A.D. 1550), all mention experiments based on after-images, and the latter, it has been discovered, actually invented the zoetrope. It became, however, quite forgotten during that age of religious zeal and

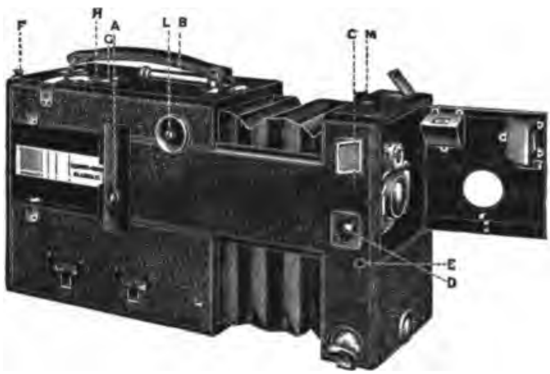


FIG. 17.—Telephoto Cornex Camera (extended ready for use). A, self-locking bolt to ensure perfect register at the two positions; B, rod carrying telephoto lens; C, button to open front; D, set off; E, pneumatic tube hole; F, back door bolt; G, changing lever; H, automatic indicator hole; L, clamp for securing front at intermediate positions.

superstition, and nothing more was done in this direction until the first half of the nineteenth century, when the subject was taken up seriously by Brewster, Wheatstone, and above all by Plateau and Stampfer, who reinvented the zoetrope.

This latter consists of a band of cardboard bent round the circumference of a circular disc. On the inside a series of figures or photographs are put, representing all the phases of a complete cycle of movements, such as a trotting horse, a juggler throwing balls, etc. Between each of the pictures is a hole or slit. On the disc being rapidly rotated, each one of the slits passes across the pupil of the eye, which is placed in position in front of the band, with the result that each of

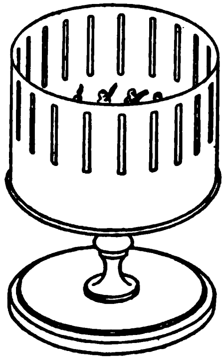


FIG. 18.—Zoetrope (early form).

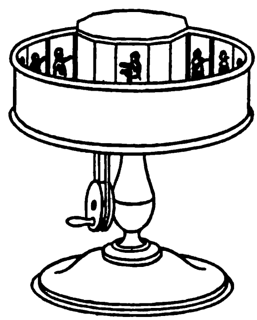


FIG. 19.—Zoetrope (later form).

the phases follows so rapidly that before the impression of one of them has died away the next takes its place, so that the figure seems to move uninterruptedly in a perfectly natural manner (Fig. 18).

The objection to this form is that the figures appear to move in the opposite direction to the slits, which causes them to appear distorted; in other words, they appear to be drawn out horizontally, *i.e.* broader than normal. If, on the other hand, the band is revolved vertically, *i.e.* round a horizontal axis, and the figures drawn so that they appear upright when the disc is rotated, they will appear distorted lengthways, *i.e.* longer than normal. This can be readily observed in the instantaneous photographs taken with a Thornton Picard roller-blind shutter when released vertically, examples

of which occur in the illustrations in any of the back numbers of the *Photographic Almanac*. To obviate this, Reynaud invented the praxinoscope. This consists of a polygonally shaped cylinder, which occupies exactly half the diameter of the outer band (Fig. 19). Each face of the polygon corresponds to one of the pictures, and consists of a plane mirror. This reflects the image nearest the observer. Now, as the distance between the picture and its mirror is exactly a quarter of the diameter of the circular band, its image will appear the same

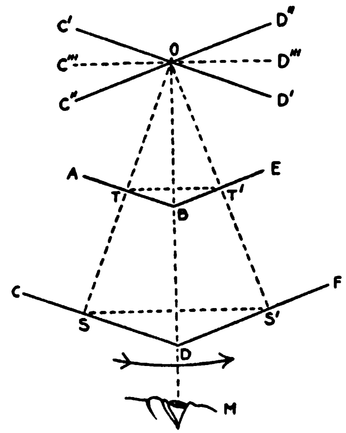


FIG. 20.—Diagram showing the theory of Reynaud's Praxinoscope. O = centre of rotation; AB, BE two mirrors forming two sides of the polygon; CDF are two pictures opposite them. When a picture is in the position SS' the mirror directly faces the eye, and the image appears to be at C''' D''', its vertical line coinciding with the axis of rotation. In the same way a picture at CD is imaged at C'D'. (Copied by permission from Hopwood's "Living Pictures.")

distance behind, *i.e.* at the axis of rotation, which is the only fixed spot in the whole apparatus. Consequently the central lines of all the images will coincide, and they will not shift their position as a whole. Hence there will be no distortion.

Reynaud placed the stereoscopic pictures in pairs on a large drum (Fig. 21), and observed the images through a pair of peepholes provided with prisms bases outwards. In this way he contrived to make the moving objects appear in stereoscopic projection. Marey, in his marvellously life-like projections,

used actual models of the animals in miniature, each one being modelled from the photograph of each particular phase.

In 1826 Brewster invented the thaumatrope. This consisted of a card on each side of which a different object was printed, *e.g.* a cage and a bird. By attaching a cord to the middle of each side and twisting it, the two objects could be seen at the same time and in the same place. Claudet improved on this by using a very thick card and attaching the strings to the side opposite the picture. By this means one object, A, appeared to stand out in front of or behind the other, B, according as to whether the pictures are arranged as in Fig. 23 (1) or Fig. 23 (2).

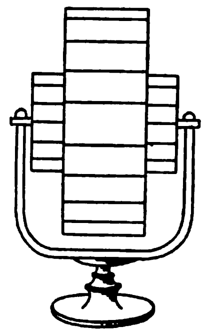


FIG. 21.

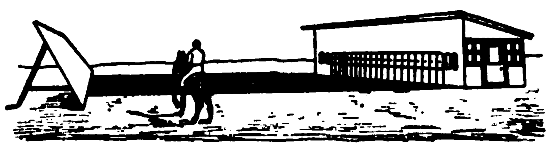


FIG. 22.—Muybridge's method of photographing the movements of a horse by means of a series of cameras (along the shed) which were released by electro-magnets set in action by the horse breaking the strings across its path.

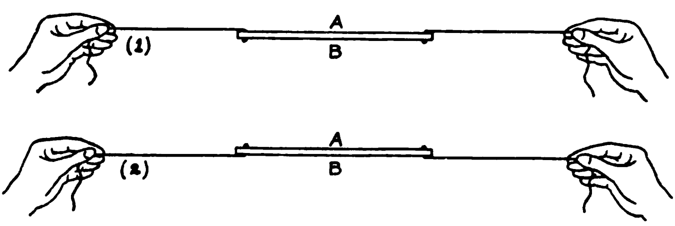


FIG. 23.—Claudet's Thaumatrope.

§ 10. **Drysdale's Speed Indicator.**—Dr. C. V. Drysdale has applied the principle of the zoetrope to speed measurement.[1]

If we take a tuning fork provided with little shutters having slits at the end of its prongs, and we set it vibrating

[1] "Accurate Speed Frequency and Acceleration Measurements," by Charles V. Drysdale, *Electrical Review*, September 7, 1906.

in front of a light, the latter will pass through the slits twice in each period (Fig. 24). Now the rate of vibration can be readily ascertained either from the note, or the length of its prongs since the rate is a constant quantity. Hence the number of flashes per second can be found with great exactness. If therefore we mark a number of dots round the periphery of a disc attached to a rotating spindle, these dots will appear stationary when viewed through the slits of the fork, provided the time

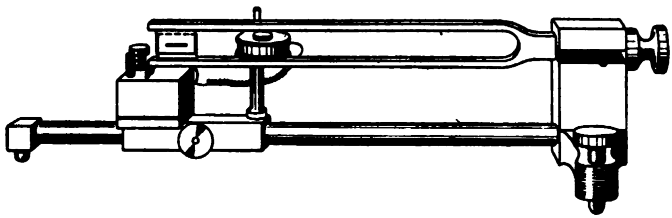


FIG. 24.—Electrically-driven Tuning-fork with Slits.

taken for one dot to occupy the position of the next, is exactly equal to the time between each successive flash of light.

Let n = vibrations of the fork per second;
N = number of dots or geometrical angles round the disc;
s = number of revolutions of the shaft per minute; and
m = the common multiplier.

Then, obviously

$$s = m\frac{120n}{N} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [5]$$

the 120 being 60 multiplied by 2, since each period of vibration lets through two flashes of light.

If m is a whole number 1, 2, 3, etc., the row of dots will appear single; if $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$, the row will appear double; if $\frac{1}{3}$, $\frac{2}{3}$, $1\frac{1}{3}$, $1\frac{2}{3}$, $2\frac{1}{3}$, etc., treble.

Example.—A fork is employed which vibrates 60 times per second. This will give 60×120, or 7200 flashes per minute. If the disc has 12 dots it will appear stationary for speeds of $\frac{7200}{12} = 600$, 1200, 1800, 2400, etc.; but double for speeds of $600 \times \frac{1}{2}$, $600 \times 1\frac{1}{2}$, $600 \times 2\frac{1}{2}$, *i.e.* 300, 900, 1500, etc.; and treble for speeds of $600 \times \frac{1}{3}$, $600 \times 1\frac{1}{3}$, $600 \times 2\frac{1}{3}$, etc., *i.e.* 200, 800, 1400, etc.

Since dots are not easy to see at a distance, Dr. Drysdale

hit on the ingenious device of placing a white regular figure inside the disc, of 3, 4, 5, 6, etc., equal sides (Fig. 25). These are plainly recognizable at a considerable distance off.

Thus, in the above case, a *triangle* appears single for speeds of $\frac{7200}{3}$ or 2400, 4800, etc.; a *square* for speeds of 1800, 3600, etc.; a *pentagon* for speeds of 1440, 2880, 4320, etc.; a *hexagon* for speeds of $\frac{7200}{6} = 1200$, 2400, 3600, etc.

In the same way, if it be desired to test each 100 revolutions, and the tuning fork has 50 vibrations per second, then a 30-pointed figure may be added (as in Fig. 25), which will appear single for any even, and double for any odd multiple of 100 revolutions, while the other figures will indicate what the

Fig. 25.—Drysdale's Geometrical Speed Disc.

particular speed is. On this point Dr. Drysdale writes: "For the calibration of speed indicators, such a device is probably the most perfect and convenient that can be employed. All that is required is a small motor (Fig. 26), to which the speed indicator may be attached, and the other end of which bears a disc with the design on it. A tuning fork with slits fixed in front of this disc is set in vibration, and the speed of the motor regulated until any desired figure is stationary. It is possible in this way to regulate the speed to an accuracy of 1 : 10,000." To test the speed of a motor at any intermediate value, Dr. Drysdale employs a conical roller, similar to that shown in Fig. 27, fixed to the motor, on which a disc, having the selected design, rolls. Whatever be the speed, one or the other of the figures on the disc may be made to appear

stationary when viewed through the shutters of the vibrating fork by traversing the disc along the roller, thereby gearing its speed up or down by any desired ratio to that of the motor, and the speed is read off on a direct reading scale which may be calculated once for all.

Another and better way which Dr. Drysdale has adopted is to put an electro-magnet in series with the fork which runs the conical roller in synchronism with it (Fig. 27). By looking at a design on the motor shaft through the slits in a disc rolling on the cone, the speed can be read off on a uniformly divided scale to an accuracy of 1 : 1000, and without attaching anything but the design to the motor shaft. Dr. Drysdale has had the

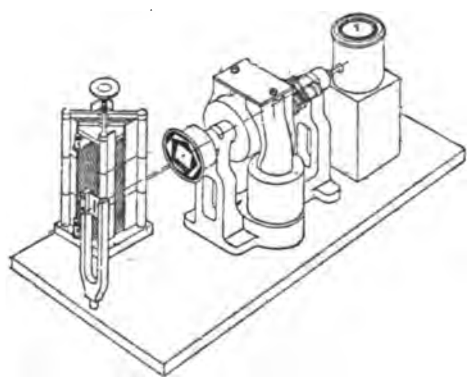


FIG. 26.—Calibrating device, copied by permission from Drysdale's paper.

design (Fig. 25) printed on cards that may readily be fixed to any shaft. A shutter speed tester on this principle was constructed and patented some years ago, but I cannot find it at the patent office, nor can I find it in the market. But with a little ingenuity Dr. Drysdale's admirable invention may be applied to testing the speed of shutters or even motor cars.

Testing Speed of a Motor.—It is possible to calculate the number of miles per hour a motor car is travelling by means of Dr. Drysdale's method. Since there are twelve spokes to each wheel, and the diameter of the wheel is nearly always 32 in. then obviously $\frac{1760 \times 3 \times 12}{32\pi}$ will give the number of revolutions per mile $= 630$, and if the car is travelling

20 miles per hour, in one minute it will have turned 210 times. Using our formula, $s = m\,\frac{120n}{N}$, we find that if a policeman on the look-out were to employ a tuning fork vibrating 42 times per second, the spokes would appear stationary for speeds of $\frac{2520}{12}$ or 210 revolutions, *i.e.* when the car is travelling 20 miles per hour. Of course, the spokes will also appear stationary for 420 or 630 revolutions, *i.e.* when the car is travelling 40 or 60 miles per hour, but not for intermediate speeds. Thus, we have a very accurate method of estimating the speed, as any one by inspection can tell the difference between a car travelling

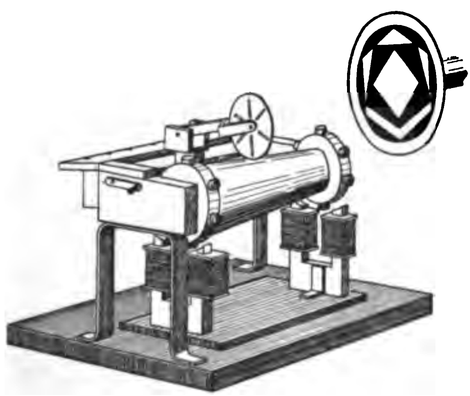


Fig. 27.—Dr. Drysdale's roller stroboscope, copied by permission from his paper (Fig. 4, p. 7).

at 20 or 40 miles per hour, but not between, say, 20 and 25 miles per hour. By using two forks of slightly different vibrations, one in each hand, any exceeding of the speed limit can be determined, but it is highly improbable that it would be received as evidence in court.

§ 11. **The Kinematograph,** which is the modern development of chronophotography, is the outcome of innumerable inventions. To enumerate the various patents and varieties of these instruments would fill a volume. (Those readers who wish to acquire a comprehensive knowledge of the different instruments will find them most admirably and exhaustively treated in Hopwood's "Living Pictures," published by the Optician and Photo Trades Review, 123, Fleet Street, E.C.)

The kinematograph consists of two instruments. First, the producing apparatus, or camera; second, the projecting apparatus, or lantern.

1. *The Kinematograph Camera.*—The object of this machine is to pass a strip of celluloid, coated with sensitive emulsion, behind a rapid short focus lens at a uniform rate of speed, so as to produce a succession of pictures containing figures in motion, and convey the sensation of uninterrupted natural movements to the observer.

The necessary mechanism is usually actuated by means of a crank turned by hand at the rate of two to two and a half

FIG. 28.—Interior Mechanism of Urban's Model D and DX Bioscope.

revolutions per second. In a few machines the rotation is mechanically performed by a train of clockwork or electric motors from accumulators. In either case, about 16 or 20 fresh surfaces should be exposed every second. This, when developed, will give a film 35 mm. or $1\frac{3}{8}$ in. wide (the actual picture being 1 in. (25 mm.) wide), and $\frac{3}{4}$ in. (18,5 mm.) in height, so that one minute's uninterrupted exposure will require $16 \times 0{,}75 \times 60 = 60$ ft. of celluloid film, and a like quantity for the printed positive.[1] The film is perforated on each side by

[1] Mr. Sanders, who has had a large experience in these matters, informs me that the cost of producing 60 ft. of celluloid film positives (including the negatives) of the full (professional) size, may be reckoned at £3. In other words, 10 minutes' uninterrupted exposure of film will involve an outlay on the part of the photographer of £30.

minute holes, $\frac{7}{16}$ in. apart, in which a wheel with sprocket teeth engage, and by its rotation carry the film along the gate. The film is unwound on one roller, and rewound, after exposure, on a second roller, both being in a light-tight box, and kept taut by an idle pulley or similar contrivance (see Fig. 28).

FIG. 29A. FIG. 29B.

Urban Bioscope Camera.

As fixed on the "Handy" Tripod. As fixed on "Maxim" Tripod.

The lens varies from 1 in. to 3 in. in focus, and should work at from F/22 to F/4, F/3 (or even F/2 for certain kinds of work). (See p. 70.)

The Stand (Figs. 29A and 29B) in some respects resembles a theodolite stand, being particularly rigid. All the best types are provided with a crank handle, by means of which the operator can steadily rotate the camera round a vertical axis, so as to keep the object in the field. To do this a view-finder is hinged to the top of the camera (not shown in the figure). In

the "Maxim" model (Fig. 29B), in addition to the azimuth motion, the camera can be tilted up or down, but such motion is not often required.

The working of the instrument is very simple. All the operator has to do after the camera and films are adjusted and n working order, is to rotate the camera so as to keep the object in the field with the one hand, whilst he turns the camera crank with the other, so as to keep the film running behind the lens at a uniform speed.

The following instructions and precautions issued by the proprietors of the Urban Bioscope Camera are reproduced here by their kind permission. They are, for the most part, applicable to any of the bioscopes on the market.

Load your Film Boxes in a dark room by a safe ruby light. Place film roll over spindle after withdrawing wooden spool. Slip end of film under roller inside box, through slot, *making certain that emulsion side of film is uppermost and faces the lens* when run through the camera. Film as supplied is rolled with emulsion on the inner side which should thus protrude from the box in the proper manner. Make certain that film box cover is firmly closed and locked before leaving dark room. To prevent the end of the film from slipping back into the box, it is advisable to make several pleats or accordion folds in the end.

To Load the Camera, place box on the top division and screw firmly into position. Then thread the camera mechanism as shown in illustration, not forgetting to leave a loop of about 1½ in. between the top and lower sprocket where the film passes through the gate. To open the gate push back the focussing tube, raise the gate spring catch, swing back the gate, clean the pressure glass, turn the handle until the movement pins protrude through their channels, insert the films over these pins, making certain that the afore-mentioned top and bottom loops are equal. Close the gate and push the focussing tube into its proper position. Pass the end of the film over the lower sprocket, making certain that the sprocket pegs engage the perforation accurately. Pass the end under the lower pulley and into the lower film box, then insert end under the brass clip of wooden spool. Turn the handle of the camera one or two revolutions to see that everything is working in order, then close and lock the lower film box.

To focus.—The most certain manner of focussing is to

view the object directly through the back of the film, provided you have a good light sufficient for this purpose. The most satisfactory way, however, is to insert a short piece of matt surface film (which answers the purpose of ground glass) in the film gate by temporarily removing the sensitized film, which can be pushed outside the closed gate during this operation. Put the focussing tube again into position, remove the metal cap from the end of the eyepiece, and rack your lens until the image in view appears absolutely sharp. You now remove the matt film, replace the coated film, insert cap in the eyepiece of the focussing tube, and push the latter gently into the camera as far as it will go.

Preparing to take the Picture.—While you are focussing you should adjust your camera for position, always keeping the camera absolutely level with the subject, unless the latter be taken from an elevation. Now set the dial at zero, so that you will always know how much film you have in reserve. See that your tripod is firmly fixed into the ground, and that the camera is tightly screwed to the top of the tripod, to prevent any oscillation. Immediately before commencing to take the view, judge your light, and arrange your stop diaphragm in lens accordingly. To judge the illumination on the film, you must now glance into the view-finder tube to the right of the lens, by removing the cap, as in the focussing tube, which will assist you to form an estimate of the quality of the light. The revolving shutter can be adjusted by removing the front section of the camera case to which the lens is attached. *Always photograph your views with the sun behind the camera*, if possible. To take the picture with the sun facing the lens is certain to produce an unsatisfactory result.

Taking the Picture.—Turn the handle evenly at the rate of two complete revolutions per second, which is equivalent to sixteen separate exposures, the minimum speed allowable to procure even movement of the objects photographed. A less speed than this would result in dislocated or jerky movements of the objects on the film when projected on the screen. (IMPORTANT.—*A funeral procession, in order to assure natural motion, should be taken at precisely the same speed as a race or an express train.*) Should your film box contain one 150-ft. roll, and after exposing, say 75 ft., you intend taking further subjects on the remainder, punch a few holes in the film by pulling out the brass knob marked film punch on the camera case, thus

enabling those who have the development of the film in the dark room to cut it at the punched holes, as each distinct exposure should be separately developed. One can feel a punched hole in the dark, whereas any other mark is most difficult to discover.

Reloading the Camera.—To reload for further exposures, after exhausting the film from the top box, remove the now filled box. Transfer the upper film box, which is now empty, into the lower section. Insert another filled box into the upper section, and repeat the operation as previously directed. All film boxes supplied with the camera are interchangeable.

Don't Forget

To replace focussing tube and view-finder caps after using, otherwise you fog all the films you are exposing.

To close all catches, thus assuring boxes being light tight before you leave the dark room and after loading and threading the camera.

To oil the mechanism and revolving shutter bearings occasionally. This does not mean the sprocket drums or any surface with which the film is likely to come in contact.

To clean the pressure glass, film gate and plate and the interior of the camera, as the slightest particle of accumulated dust will scratch the surface of the very sensitive film.

To make certain, before turning the handle, that the object you intend photographing comes within range of the instrument, otherwise you are wasting film.

To include as picturesque a background as possible, as this enhances the value of your picture.

That, in case of accident to the wire film-take-up strap, the same must be replaced or repaired by removing the front section of the camera to which the lens is attached, and inserted over the pulley from this position.

That the object of an animated picture camera is to take animation, and plenty of it: the more action there is in the picture, the more successful will be the subject, nevertheless, let your performers move naturally and deliberately, and not in a desperate hurry, if the piece is a pre-arranged one.

That too much sky is detrimental to the reproduction of an animated picture, just as too much foreground without action therein is equally objectionable.

To place the camera not less than about 20 ft. from the nearest object that you wish to include in your view.

It is impossible to say which is the best machine to-day, but, as Hopwood[1] remarks, "accuracy of workmanship has quite as much, probably more, to do with results than the principle of the machine." We append (Fig. 30) an illustration of one of the lightest and most up-to-date forms we know of. It is largely used by professional photographers. The complete outfit as shown in the figure will cost about £37, *i.e.* camera, tripod, revolving stage and cases, but the Urban Co. supply an outfit which will do excellent work on full-sized film for so small a price as £7 10*s*.

FIG. 30.

The best speed to take living objects, according to Mr. Sanders, varies between sixteen and twenty pictures per second. In exhibiting, the speed may be slightly increased. At the Alhambra, I was informed by the operator that he got the best results with a speed of eighteen to twenty pictures per second, but this may be considerably increased. The chief points to attend to are: (1) Evenness of lighting; (2) Absolutely uniform speed; (3) Great care in avoiding dust spots and marks on the film both before exposure and during development; (4) Absence of flicker; (5) Some means by which the travelling film is rendered optically stationary. This may be effected, as in the praxinoscope, by means of a mirror-drum, which, being in continual rotation in one direction, renders all the images optically stationary. Hopwood says: "A continually revolving camera taking a continuous view of the whole horizon, or such part as is left unshielded, needing no shutter, and leaving no period of darkness, having a film in constant motion yet optically stationary, may conceivably be the groundwork upon which

[1] "Living Pictures," p. 233.

a perfect, though somewhat expensive, instrument may be built." In any case, the instrument should bring each fresh piece of film into position without shake, and so that the exposure should be as long and the change as short as possible

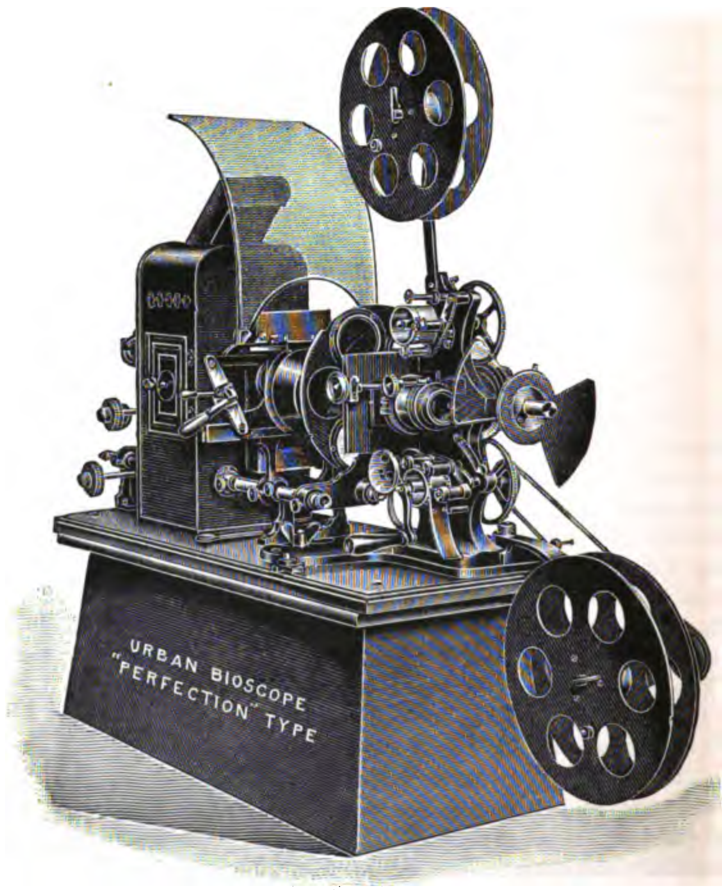


FIG. 31.

between each exposure. In Newman & Guardia's kinematograph 90 per cent. of the total time is devoted to exposure.

2. *The Kinematograph Projecting Apparatus.*—This is a slightly more complicated mechanism than the former, and

requires the addition of a powerful luminant, usually an arc lamp or oxy-hydrogen jet.

Fig. 31 shows the latest design of the Urban Bioscope Projection Lantern, embodying every one of his latest improvements.

Figs. 32 and 33 give the details of the apparatus. These drawings will serve to explain the mechanism better than any detailed description.

One of the chief troubles of the operator is due to flicker. This might be considerably reduced if the shutter had a vignetting edge (*i.e.* long saw teeth), so that the light may be admitted to the film at the same rate as that at which it naturally fades from the eye. Very rapid travel, especially without a shutter, is apt to produce the so-called "rain" effect, which is so often seen in connection with damaged films. Urban has succeeded in reducing flicker and blending the successive pictures harmoniously by replacing one of the two flanges of the rotating shutter by a similar-shaped piece of violet glass. This prevents the obtrusiveness of the contrast between light and darkness.

In my opinion an arrangement on the principle of the old-fashioned dissolving view, by which one picture is projected while the previous one is dying away may abolish flicker, M. Gaumont effects this with great success by means of a fan pierced with row after row of small holes. This he terms "La Grille." It appears, however, to be very effective. Mr. Hopwood pointed out to me that rapidly vibrating the open fingers before the eyes will produce the same result.

Although there are many contributory causes of flicker, want of perfect alignment or "register" of the pictures is, I believe, one of the most important, and if this is achieved colour pictures of living objects will become very popular.

Movement of the film by the Maltese cross motion is becoming the fashion, as is the "dog motion," or striker.

When inserting a new film *be sure that the film side, with picture upside down, is presented to the condenser.* It would be well to affix a tiny white disc of paper, as a reminder, on the film side of the last picture next to the sky or heads of the figures. In winding, the unmarked end should be rolled on first. If the sky or heads are upright in front of the condenser the image on the screen will of course be upside down, and if the film side face the *lens*, but the heads and sky downwards,

D

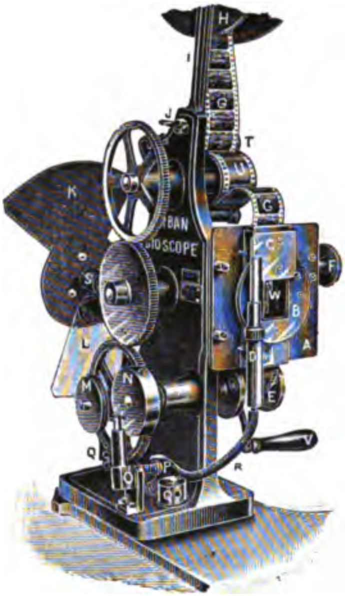


FIG. 82.

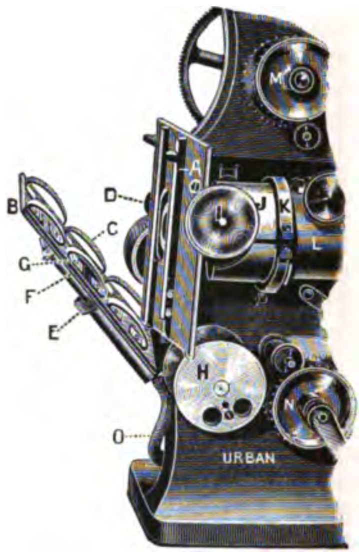


FIG. 83.

Detailed Portions of Bioscope Mechanism.

A, Film trap main plate.
B, Asbestos-brass cooling shield.
C, Pneumatic shutter or light cut-off.
D, Pneumatic light cut-off valve.
E, Eccentric cam or dog movement (Patented).
F, Registration adjustments thumbscrew.
G, Film strip (threaded through machine).
H, Top film reel.
I, Top film reel support.
J, Top film reel support clamp screw.
K, Opaque revolving shutter.
L, Translucent violet shutter blade.
M, Film-take-up pulley.
N, Eccentric shaft balance wheel.
O, Pneumatic light-cut-off piston valve.
P, Piston valve air pressure adjustment.
Q, Swivel base screws.
R, Indiarubber connecting tube.
S, Revolving shutter spindle.
T, Vulcanite upper film guide roller.
U, Upper sprocket drum.
V, Handle for turning mechanism.
W, Film trap light aperture.

A, Main film trap plate and guide rails.
B, Film trap plate with springs.
C, The bow pressure springs.
D, The "Hump" which prevents film buckling.
E, Light cut-off valve.
F, Pneumatic light cut-off.
G, Bow spring screws.
H, Eccentric cam or dog movement (Patented).
I, Registration adjustment screw.
J, Sight guard to lens support.
K, Adjustable lens mount holder.
L, Lens mount with rack and pinion.
M, Upper sprocket drum.
N, Lower sprocket drum with handle.
O, Indiarubber tubing for light cut-off.

the result will be an upright picture on the screen but laterally reversed. This is, in many instances, of no consequence, but in a cricket match, for instance, on the screen, the right-handed bowlers and batsmen would appear *left*-handed.

The screen should be opaque, since a linen sheet lets too much light through.

§ 12. **Projection of Moving Objects in Natural Colours.**—This has recently been accomplished by Mr. G. A. Smith by the following ingenious method. Instead of projecting autochrome films, or composite colour films, as in the Lumière or Sanger Shepherd processes, he makes use of the persistency of the retinal colour impressions to produce his combination effects. For this purpose he first makes a panchromatic film specially sensitive to red and green rays. Instead of an ordinary revolving sector, he employs a wheel divided into four sectors, the two opposite quadrants being of blackened aluminium while the lateral quadrants are fitted with a green and red glass respectively. Every fresh exposure corresponds to a half revolution of the disc so that each section of film is taken alternately through a green and a red glass. Since the ordinary number of exposures amount to about 16 or 20 per second, Mr. Smith rotates the exposure wheel at double the speed so as to get from 32 to 38 or 40 exposures per second. When the strip has been exposed throughout he makes a positive print and runs it in front of the projection lantern. In this case the positives are rotated in front of a similar sector to the one used in making the original exposures. Care must be taken to see that the sector is in the right position with regard to the picture, and to ensure this being done Mr. Smith makes a cross (or prints title) on the first green picture, and arranges it so that it is immediately behind the green glass quadrant. If this were not done the red quadrant might take its place, and the picture would appear on the screen in complimentary or reversed colours.

Thus, a French soldier with red trousers and a blue coat might now appear in green trousers and a black coat. The various colours are due to continuity of vision. If a picture be projected through the red glass and the next following through the green glass, the two colours will mix in the observer's brain centres, and the picture will appear to consist of either red or green, or yellow orange or white, according to whether the green or red is blocked out, or whether there is an excess of green over red (which forms yellow), an excess of red over green

(which forms orange), or a maximum intensity of green and red, which produces white.

I have suggested that by taking three successive exposures through three primary colour filters, viz. blue-violet, green, and red, we may get the colours to more closely resemble the original, and thus to reduce the two first sources of imperfection, viz. absence of blues and violets, and want of half-tones of colour. In this case the film travel would have to be rather faster, say 48 pictures or 16 complete changes per second, and a similar speed used in projecting them. Mr. Urban has, I believe, just designed and perfected a machine which brings the negative films and projected films into absolute alignment which he informs me has greatly improved the results first exhibited. Hitherto, these have been open to the serious defect of coloured borders around the objects, due to want of perfect superposition of the images.

It is rather remarkable that films projected alternately behind green and red discs, should so combine in the mind as to produce the sensation of an apparently pure white, since one would naturally expect to see a yellow or orange image formed, and it is still more difficult to conceive how occasionally a distinctly purple or brown sensation is produced. We understand, however, that this unexpected result is due to the precision with which Mr. Smith has divided the spectrum in the filters of his camera, and the corresponding care with which the projection colours have been paired.

I may add here, for the benefit of those who are experimenting in this direction, that it is important that the colours selected should be in the order of their persistency. Now, it is known, from after-image experiments, that in round numbers violet images remain in the field of vision twice as long as blue ones, blue images twice as long as green, green almost twice as long as yellow, and yellow about one and a half times as long as red ones. Theoretical considerations would therefore render it advisable to begin with the blue-violet, then to take up the green and finish with the red image.

§ 13. **Rules Required to be Carried Out in Public Entertainments.**—The following are the rules required in kinematograph exhibitions, owing to the inflammable nature of the celluloid films :—

1. The lantern must be constructed of metal, or lined with metal and asbestos.

2. An alum or water tank must be placed between the condenser and the film.
3. The apparatus must be fitted with a drop shutter available in case of emergency.
4. If the film does not wind upon a reel or spool immediately after passing through the machine, a metal receptacle with a slot in the metal lid must be provided for receiving it.
5. If electric arc lights are used, the installation must be in accordance with the usual rules, *i.e.* the choking coils and switch to be securely fixed on incombustible bases, and d.p. safety fuses to be fitted.
6. If oxyhydrogen gas is used, storage must only be in metal cylinders.
7. The use of an ether saturator is prohibited.
8. No drapery or combustible hangings to be within two yards.
9. Fire buckets or extinctors should be placed close at hand.

§ 14. **Photographic Gun.**—This, in its original form, was employed by the late M. Janssen, the eminent astronomical

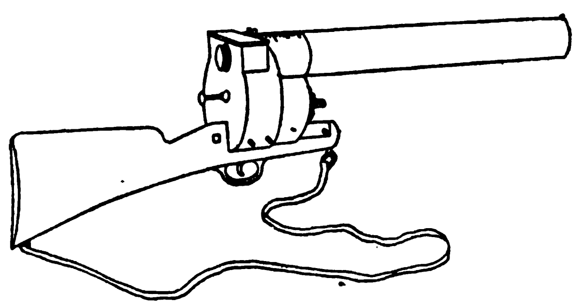


FIG. 34.—Marey's Photographic Gun.

photographer, for recording the transit of Venus. It consisted of a large disc carrying 48 plates, arranged round its circumference. This was placed at the end of a wide tube fitted with a lens. The whole, rigidly mounted, was placed under cover and directed towards a heliostat mirror, by which the apparent motion of the sun was neutralized. With this instrument, in 1874, M. Janssen was enabled to secure a series of 48 views of the transit of Venus across the sun's disc in

72 seconds. This apparatus is memorable as being the first practical chronophotographic record ever made, and the pioneer of the innumerable instruments for securing pictures in motion which have been made since (see p. 25).

This instrument was followed by Marey's Photographic Gun, with which he secured his photographs depicting the flight of birds, which he combined in a zoetrope.

The beautiful series of pictures illustrating the surface tension of a falling drop of liquid, and the subsequent splash when the drop struck the surface of the same liquid beneath, was obtained and combined in a similar way by Prof. C. V. Boys. Instead of a gun, he employed a fixed camera, behind which a very long slide (7 ft.), balanced by weights, was allowed to slide down by gravity, so as to expose without using a shutter.

FIG. 35A.

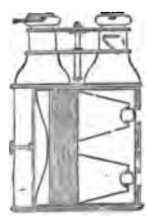


FIG. 35B.

Watson's Stereoscopic Binocular Camera. It is fitted with a pair of R.R. lenses, and the shutter works from $\frac{1}{25}$ to $\frac{1}{80}$ of a second, in addition to time exposures. The view is seen in a finder fitted to one of the eyepieces. The changing-box, which, in position, occupies one of the tubular bodies of the camera, carries 12 plates $4\frac{3}{4} \times 2$, on which stereoscopic views are taken, or, by obscuring one of the lenses, 24 single pictures may be secured.

§ 15. **Cameras Designed for Concealment.**—1. *Opera Glass (Binocular) Cameras.*—Several well-known forms of these are on the market. Watson makes a particular neat form which carries a pair of lenses, the view being taken across the body of the binocular. This enables the operator to hold the binocular to his eyes in the ordinary way, and direct it to an object at right angles to the view he desires to photograph. By this means he can entirely disarm suspicion. A mirror at 45° and peep-hole is fitted into one of the eyepieces, so that he can see the image in the erect position while taking the picture.

2. *Watch, Breast, and Scarf Pin Cameras.*—Of these the first-named is the only one of practical value. The lid of the watch opens with a spring and forms a sort of base board, while the lens, fitted to a bellows arrangement, springs forward and is supported by the lid. In general construction it resembles the ordinary folding Kodak. It takes a view a little smaller than the inscribed square of the disc.

3. *The Book Camera.*—This is a camera (Fig. 36) covered with leather, having a sham title printed on the back and side. It is thus made to resemble a book in every detail. Folding bellows, covered with white linen to resemble the edges of the book, are fitted above and below. The book opens in the centre, so as to form an equilateral triangle when the slide is placed in the groove near the edges. The lens is concealed in

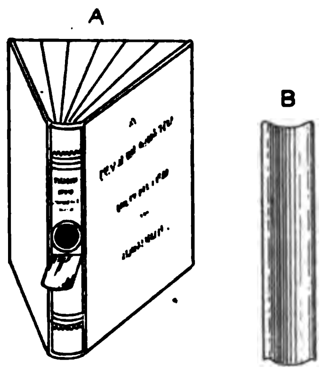


Fig. 36.—The Book Camera, showing the flap shutter which conceals the lens turned down. B is a sliding concave lid covered with rough paper to resemble the edges of the leaves of a book. It is removed to allow the camera to be opened.

the front of the book. Part of the binding is made to hinge down, and thus acts as a shutter. It forms a capital disguise, and can never create suspicion. The triangular base forms a firm support on a table, so that time exposures can be made. I could never discover the reason why it has been taken off the market, as it forms the smallest camera that can possibly be made, a half-plate size going readily into the pocket. The shutter works between or behind the lenses, and is released by a pneumatic tube fitted inside.

4. *Opera Hat Camera.*—This, as might be supposed, is the invention of a Frenchman. It consists of an ordinary opera

hat, which may be worn by the operator in the street. The lens and press-button shutter are concealed inside the top of the hat, whilst an oval padded disc, which contains the slide, is kept in the pocket. When the hat is used, the padded disc, which has a covered metal rim, presses against a folded projection about 1 in. above the rim, *i.e.* just high enough to avoid pressure on the forehead. The slide has a flap which hinges over on pressing a spring actuated by a press tube carried through the lining of the hat. On turning the hat over, the flap falls back into its place, and is caught again by the spring on squeezing the ball of the tube. It cannot take pictures larger than a quarter-plate, nor is there room for a lens of longer focus than $4\frac{1}{2}$ in. The original idea of the inventor was for use in church while kneeling in silent prayer, the hat being supported on the front of the pew or back of the chair. In this country it has not altogether fulfilled the inventor's expectations.

§ 16. **Pocket Cameras.**—In addition to the book camera, there are several forms which are remarkable for their extraordinary compactness and ingenuity of construction, among which we may specially mention the "Xit" and "Koixit" of Shew, the "Sibyl" of Newman & Guardia, the "Tenax" of Goerz (a very ingenious camera, which springs at once into focus the moment it is opened), Houghton's "Ariel," the "Minimal" of Clement & Gilmer of Paris, and "Ernemann's" pocket camera (Zimmermann). These are all admirable little cameras, and very little larger than the plates they are intended to carry. Thus, the post-card "Minimal," Houghton's "Ariel," and the "Ernemann's" pocket cameras, all of which carry plates $5\frac{1}{2}$ in. × $3\frac{1}{2}$ in., occupy far less room than the average quarter-plate camera. Indeed, they will go into any ordinary breast pocket.

With the exception of the "Sibyl," they are all very cheap in price, but, on the other hand, the "Sibyl" is so exquisitely made, and every part has been brought out to such perfection, that in the long run it is probably the cheapest of all. At the author's suggestion it is now made in quarter-plate size, and is fitted with a Tessar lens and their own shutter, which, in my opinion, is one of the most accurate and perfect that exists (Figs. 37A and 37B).

§ 17. **Slides or Plate-Holders.**—I much prefer these to changing-boxes, the latter being a continual source of trouble,

and never quite reliable. I have tried seven or eight different kinds and have never yet found one that always worked satisfactorily. In my experience they invariably get out of order when in the field after the camera has been jolted about.

Fig. 37A.

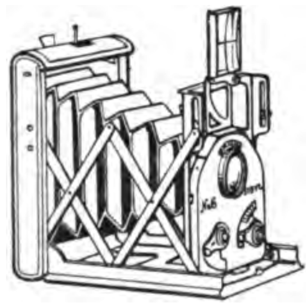


Fig. 37B.

Sibyl Camera (Newman & Guardia).

Single slides occupy little room and are generally liked, but personally I prefer the double slides, or "double-backs" as they are called. Ebonite double-backs fitted with kettleholder slides are excellent when new, as there is no possibility of the

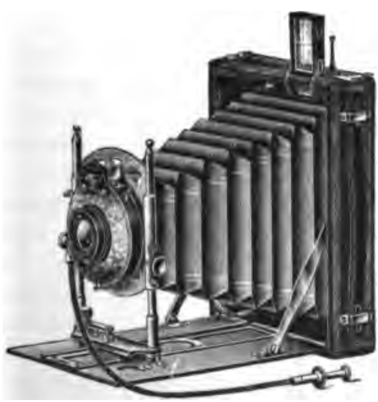


Fig. 38A.—The Ernemann's Camera (ready for use).

Fig. 38B.—The Ernemann's Camera (closed for pocket).

light being admitted at the end since the slide cannot be drawn out of the back. On the other hand, they are apt to wear between the strips and leak, and require to be frequently examined. Film backs are extremely portable, and can be

fitted to any camera, but films are not so reliable as plates, and are apt to show horizontal streaks like telegraph wires and other mysterious-looking marks on development.

Solid Backs.—Another admirable double-back is the solid form. It is generally made of wood, but I see no reason why aluminium, ebonite, or vulcanite should not be used. I had a set of these backs made some years ago in which the two flat springs which force the plate into position projected slightly beyond the ferrotype partition, so that when the lid at the end of the back is closed, it presses on the springs, and forces both plates into register. On opening the end, the springs of course fall down flat and thus facilitate the removal of the plates. The chief feature of this form is that it does not matter whether the plates are of the exact size or not, as the back allows of considerable latitude in that respect. Moreover, they admit of carriers very readily, and possess the great advantage that one can slip the plates in and out in a moment, even in total darkness. Personally, I prefer them to all other forms. My sets were made by Perken, Son, & Rayment twenty-two years ago, and I have used them ever since. I keep them in waterproof rubber cloth cases which fold over at one end, the flap being held in position by an elastic band sewn on to it.

Aluminium, brass, thick vulcanite, ferrotype plate, and black japanned mahogany are all safe, but zinc, tin, and celluloid are open to objection, since the two former give rise to emanations, or some form of chemical action, which leave marks on the plate, and the celluloid in dry weather often emits electric sparks, which also impress the plate. I have repeatedly noticed this in the high Alps. The mere act of pulling out the drawpiece will often give rise to quite a display of sparks, which any one can try for himself in the dark room if the air is very dry. Moreover, some of the wooden slides are lined with black canvas or linen, which is liable to act on the plate by reducing the silver salts, and give rise to bands or marks. They should be carefully tested before setting out on an expedition. It is well, in any case, not to leave the plates more than a day or two in the plate-holders. The backs should fit into the camera recess by means of a bayonet catch, or be pressed into position by means of a lever spring, as is usual in Newman & Guardia's cameras. In this case the plate-holder is usually very thin, and only holds one plate. The velvet which keeps the light out when the drawpiece is withdrawn should be periodically

renewed, as it is apt to get worn smooth; this applies to all plate-holders. The best modern backs are fitted with two velvet traps, one behind the other, so that when the slide is inserted obliquely it will not let light in, as the inner trap is closed. This is lifted up by the slide as it is pushed further in. The writer strongly advises the amateur to have this most useful invention adopted to all his backs in which the drawpiece pulls right out. Perken & Son fit all their backs with an inside flap (even when the drawpiece is not removable). This effects the same purpose.

Many years ago I devised a small flap of velvet cut about half an inch wide, and the same length as the drawpiece is wide. This was doubled on itself and the two margins glued along the end of the drawpiece so that it formed a loop of velvet across it. As the drawpiece was pulled out as far as it would go, it swept the film of the plate free from dust, at the moment before exposure. Of course it prevented the drawpiece from being pulled right out of the back; but I consider that rather an advantage, as it prevents the possibility of light getting in. I never saw it adopted by camera makers, but it should prove of service when travelling along dusty roads.

§ 18. **Camera Stands.**—These are best made of aluminium, ash, or mahogany. For quarter-plate cameras a three- or four-jointed aluminium collapsible tube stand is useful. The tall walking-stick patterns are handy in touring. A large ferrule at the foot of the stick pulls off and allows the three legs, which fit together to form the walking-stick, to open out in a tripod position. The stick should not be less than 4 ft. long. For box cameras and half-plate folding cameras, a threefold ash stand with a large wooden head is necessary. For still larger sizes, or for telephoto work, a twofold mahogany stand, *i.e.* having only one sliding piece to each leg, is required. In this form the tension of the hinge between each leg and the head is regulated by a binding-screw, as in most theodolite stands. This greatly increases the rigidity, as this is the weak spot of all ordinary stands. To prevent slipping fix corks to the feet.

In order to save time when fitting the screw which holds the camera to the head, it is a good plan to screw a spare lens flange to the camera baseboard, having the screw hole for its centre. Then turn a circular groove into the top of the tripod-head a shade larger than the flange and having the binding-screw for the centre. This enables the operator to place the

camera instantly in correct position on the tripod, and the flange keeps the camera steady when rotating it.

To prevent losing the screw, chuck it in a lathe and cut away all the screw thread except the terminal third of an inch. Next drill four holes in a halfpenny, three equidistant round the margin by which to screw it *underneath* the tripod head, and one in the centre to admit the screw. Now turn a thread in the

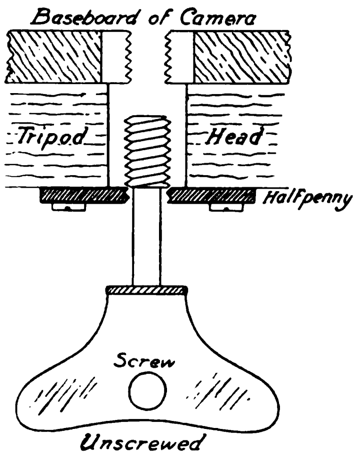


FIG. 39A.

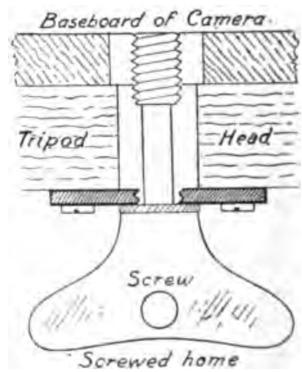
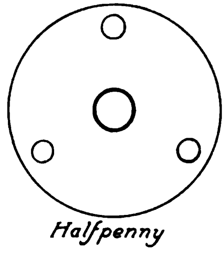


FIG. 39B.



The author's device for fixing the screw rapidly to the camera, and preventing it from dropping out of the camera head.

centre hole, which will just allow the thread of the binding-screw to pass by screwing through it. When the camera is placed in position on the tripod-head, the screw can be pushed up through the hole above the halfpenny and then screwed home, the shoulder of the screw binding against the halfpenny. When the camera is unscrewed, the screw will drop down flush with the top of the tripod-head, but cannot be lost, being

retained by the halfpenny. I invented this idea over twenty years ago, and have used this form of screw ever since.

Many cameras are fitted with a revolving turntable which takes the place of a tripod-head. This does well enough for small cameras under half-plate size; but for large cameras a turntable is a nuisance, as you are compelled to hold the camera in one hand, or lay it down on the ground, whilst you are attaching the legs. A screw which can be clamped on to the head of an ice axe is often useful in Alpine photography. This will allow of a press-ball exposure of from 1 to 2 sec. without shaking the camera if one end of the haft be stuck in the ground and the other end held close to the body while keeping the eye on the view-finder during the release of the shutter.

CHAPTER II

THE LENS[1]

§ 19. **Examination of a Simple Plano-Convex Lens or Bull's-eye.**—In studying and testing photographic lenses, it is just as well that the student should make himself familiar with a simple lens. If a plano-convex spectacle lens of short focal length (Fig. 40A) be fitted to a camera, with the flat surface outwards, and the image of any bright object, such as a candle or the moon, be examined on the screen, however carefully one focusses it will seem to be slightly hazy, even in the centre of

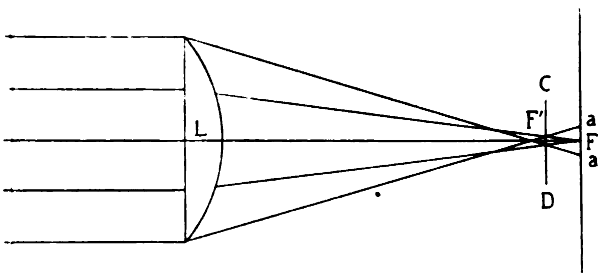


FIG. 40A.—Diagram showing the formation of spherical aberration by a plano-convex lens.

FIG. 40B.—Halo at F.

the field, the image being surrounded by a halo or aureola at F (represented by a dotted circle in Fig. 40B). This is due to spherical aberration, and the diameter of the disc or halo is sometimes called *lateral* aberration. It is due to the out-of-focus rays which pass through the periphery of the lens forming a circle round the central focus formed by the central rays. The distance F′F between the focus formed by

[1] The calculations relating to lenses in this chapter are treated in a very elementary manner. Those readers who desire a more detailed knowledge of the subject will find it treated in clear and simple language in Lionel Laurance's recent work on General and Practical Optics (Orthos Press).

the peripheral rays, F′, and that formed by the central rays, F, is known as *longitudinal* aberration. The circle of least confusion lies somewhere between these two points, F and F′, in the above figure, at about the plane CD. This is the spot of least aberration.

Now reduce the aperture of the lens with consecutive rings of black paper, and the halo will become less and less as smaller rings are added, until at last it disappears.

These experiments show that lateral aberration diminishes with the aperture. In fact, it is proportional to the cube of the diameter of the aperture, while the longitudinal aberration, *i.e.* the distance between the two focal planes is proportional to the square. Hence the necessity of stopping down a simple lens. But the aberration can be reduced in other ways, for if we turn the lens round so that the curved surface faces the object, the halo will be reduced to nearly a quarter the size. If we substitute a crossed lens whose radii are in the proportion of one to six, and having the deeper curve towards the object, the halo will be still further reduced, in fact the aberration will be least possible supposing the refractive index = 1,5—viz. that of ordinary crown glass. We must add this proviso, for were the lens of greater density (with an index of say 1,6) the proportion between the two curves would have to be much greater, so that the lens would need be nearly a plano-convex. If we used a still denser glass, we should want the back surface to be slightly curved the other way, in fact, concave.

Take the camera into a dark room, place a candle at the further end of the room, then turn the curved side of the plano-convex lens towards the light. On approaching the candle the aberration on the screen (which must be moved backwards) increases, until the candle is at the focus of the lens when the aberration is at a maximum. Now turn the lens round with the flat surface to the light, and the aberration is reduced to nearly a fourth the amount at once. The reason for this is that the lens is in reality a prism, or, rather, made up of an infinite number of prisms, having their bases at the centre of the lens, and the least possible aberration occurs when the prisms are in position of minimum deviation. This is the case when the convex surface is turned towards parallel rays (in other words, when the light is remote compared with the focal length of the lens), but for rays divergent from a point at the principal focus of the lens, the flat surface, or in

the case of a crossed lens the flatter surface, must be turned towards the light. These facts are most important, and they form a clue to the manner in which a bull's-eye condenser should be used to the best advantage.

Place your camera at the end of the table, and at the other place a row of seven cards, numbered successively, in parallel

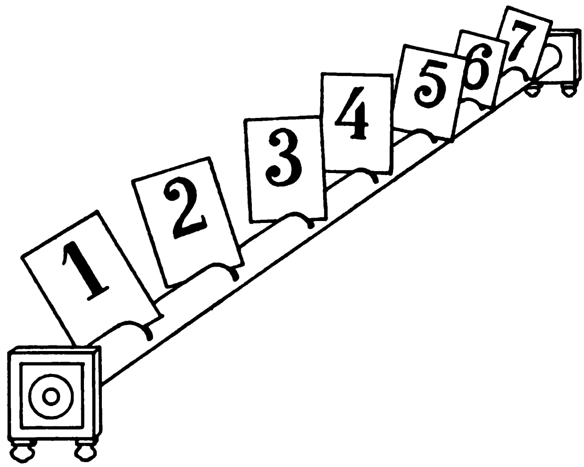


Fig. 41.—Card test for achromatism.

slots sawn across a bar of wood, one behind the other, at intervals of an inch, so that the print on each card can be seen on the focussing screen (Fig. 41). Focus carefully for the centre card, expose and develop the plate. It will be found that No. 4 card focussed is now out of focus, and another card nearer will be sharp. A simple lens, therefore, has two foci separated by a perceptible distance, one where the brightest visual (yellow) rays meet, called the visual focus, the other somewhat nearer the lens, where the blue-violet rays meet, which is called the actinic or chemical focus, because here the rays which affect the sensitive plate form an image, and they are only slightly visible to the eye. Consequently, to get a sharp negative, the plate, after focussing, must be moved towards the lens a certain distance.

Some say this distance should be $\frac{1}{50}$th of the focal length of the lens, others $\frac{1}{30}$th, but the discrepancy is easily accounted for, since the distance the plate should be shifted depends on a number of factors, such as the aperture, the focal length, the

distance of the object, the form of the lens, and its refractive and dispersive indices. As a general rule, the distance should equal $\frac{1}{50}$th of the focal length for distant objects, and $\frac{1}{40}$th or $\frac{1}{30}$th for near objects. But it can be calculated from the difference between the focal length of the lens for the visual and actinic light, if the refractive indices for the yellow and violet rays be known. Thus, in a plano-convex lens, since

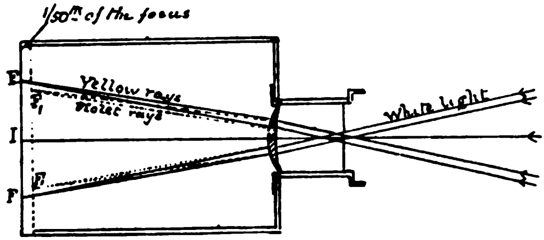


FIG. 42.—Diagram showing the two foci produced by the splitting up of white light by a lens.

$r = 12$ in., the yellow index $= 1{,}5$, and the violet $= 1{,}515$; then $F = \frac{12}{0{,}5} = 24$ in. for the yellow, and $\frac{12}{0{,}515} = 23{,}53$ in. for the violet. The chemical focus thus differs from the visual by 0·47 in., so that, in this case, the plate must be moved forwards $\frac{0{,}47}{24}$ or $\frac{1}{51}$ of the focal length of the lens. In practice, the plate must be moved considerably more, as an average must be struck between the focus at the centre, and at the edge of the plate, owing to the curvature of field.[1]

Lastly, the effect of the position of a diaphragm on these aberrations should be noted. Mount a plano-convex lens in the camera with the flat side out, and without a diaphragm. Focus for best definition, and it will be seen that no part is quite sharp, but the definition is better round the centre. Place a diaphragm whose aperture is about the $\frac{1}{12}$th F close up against the lens. This will give a sharp central definition, but only over a small area. Now slowly withdraw the diaphragm, and observe how the definition improves over a gradually increasing area, until a certain point is reached, when no further improvement can be made.

[1] It has been pointed out by Mr. George Brown, that if a yellow screen and an orthochromatic plate be used, no correction for chemical focus need be made when using a spectacle or other single lens (see "The Lens," by Bolas and Brown, a book which teems with valuable practical hints).

General Properties of Thin and Thick Lenses.

The author has adopted the positive sign (+) to represent the power or focal length of a convex lens as well as the curvature of a surface which tends to converge the incident light, while the negative sign (−) is prefixed to the power or focal length of a concave lens and to the curvature of a surface which tends to diverge incident rays, in accordance with the practice of many foreign physicists of eminence.

§ 20. **Thin Lenses.**—If light from any point of an object, O, pass through a lens and is brought to a focus, I, then I will be the image of O, and the two points will form conjugate foci, because however you shift the object O, the image I will move likewise, not to the same extent, but always just so far that the reciprocal of the distance of the object from the lens, added to the reciprocal of the distance of the image, will be exactly equal to the reciprocal of the focal length of the lens. Or if a = distance of object from the lens and b the distance of the image, then

$$\frac{1}{F}=\frac{1}{a}+\frac{1}{b} \quad . \quad . \quad . \quad . \quad . \quad . \quad [6]$$

Or, to put it in another way, if we represent the power of the lens to alter a wave front by D (which may be expressed by the reciprocal of its focal length 1/F), then that power will always be found to be divided up between the distances from the lens of object and image respectively, so that if we express the distance of the object from the lens by its power, p, which is the reciprocal of this distance a $\left(i.e.\ \frac{1}{a}\right)$, and the distance of the image from the lens by its power, p', which is the reciprocal of this distance, b $\left(i.e.\ \frac{1}{b}\right)$, then

$$D=p+p' \quad . \quad . \quad . \quad . \quad . \quad . \quad [6a]$$

This is rigorously true, whatever be the shape or nature of the lens, provided the image is on the opposite side of the lens to the object. In this case the image will be inverted and real, *i.e.* it can be received on a screen.

If the image be formed on the same side of the lens as the object the image cannot be received on the screen. It is then called a virtual image, and will be erect. In this case the reciprocal of the focal length of the lens will be exactly equal

to the difference between the reciprocals of the distances of O and I, or

$$\frac{1}{F}=\frac{1}{a}-\frac{1}{b} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [7]$$

Or, to put it in another way, if a has a stronger dioptric power than the lens (in which case the object lies nearer the lens than F/1, *i.e.* within the focus), then b must have a corresponding negative value, and the image will be a virtual one, and lie on the same side as the object. This may be expressed by the formula

$$D = p - p' \quad . \quad . \quad . \quad . \quad . \quad . \quad [7a]$$

Now, according to Huyghens' principle, each luminous point of an object will scatter light in all directions, and the rays will travel in straight lines in the form of undulations, or waves. Each little wave will form a sphere of energy. The circumference of each tiny sphere will form the starting-point of the next sphere, but since all the waves travel at the same rate, the crests of each row of spheres will form the circumference of a big sphere, the centre of which is the object-point. This circumference is called the wave front. When this wave front meets the curved surface of a lens it suffers retardation. If the curved surface has its convexity turned towards the wave front it will tend to flatten it out, because the middle of the wave front will be retarded, while the sides will travel unimpeded until they reach the lens. Such a curved surface is called *positive*, because it tends to the formation of a positive, or real, image. When the flattened wave reaches the second surface of the lens another change occurs. If the curved surface be concave on the side of the wave front, the sides of the latter will have escaped into the air and resume their initial velocities, while the centre of the wave is still struggling to get through the lens. In this case the effect of the second surface will be to intensify that of the first one, since it also acts in a positive manner. The second surface is therefore called positive for the same reason. If the two curves jus succeed in flattening out the wave front to a plane surface, the wave front will travel on to infinity and never come to a focus at all. If, however, the second curve is strong enough not only to flatten out the wave but to bend it in the opposite direction, it will form a concave surface, and the wave will form a focus at the centre of that curve, which is called the image point of the object. In this

case the image is real and can be formed on a screen on the opposite side of the lens to the source of light.

If the first surface of the lens present a concave aspect to the wave front, it will not oppose but add to the curve of the wave front. It is therefore called a *negative* surface. If the second curve is positive and has a shorter radius than the first curve it will have more power, and after neutralizing the effect of the first curve it will be able to bend the wave front in and bring it to a positive focus as before. If it has a longer radius, and therefore endowed with less power, the total effect will be a negative one, and the image may be traced back in the direction of the object and will form a negative image. This will be erect and virtual, and may be situated anywhere between infinity and the object side of the lens.[1] Instead of expressing the lens in general terms by its power, we may resolve the latter into two factors, viz. curvature and refractive index, or if the lens has a sensible thickness, into three; viz. curvature, index, and thickness. We may express these conditions where the image is real by the formula

$$\frac{1}{F} = (\mu - 1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right) \quad . \quad . \quad . \quad . \quad [8]$$

where F = focal length of the lens, μ its refractive index, and r_1 and r_2 the radii of the first and second surfaces of the lens.

In the second case, in which the second curve is negative, we must alter the sign and write

$$\frac{1}{F} = (\mu - 1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \quad . \quad . \quad . \quad . \quad [9]$$

or if both curves are negative, we write

$$\frac{1}{F} = (\mu - 1)\left(-\frac{1}{r} - \frac{1}{r_2}\right) \quad . \quad . \quad . \quad [10]$$

in this case, F is negative and the focus is a virtual one.

From what we have stated at the commencement of this paragraph, we may express the above formulæ, [6, 7, 8] and [9] respectively, by

$$D = p + p' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [11]$$
$$D = p - p' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [12]$$
$$D = (\mu - 1)(p + p') \quad . \quad . \quad . \quad . \quad [13]$$
$$\text{and } D = (\mu - 1)(p - p') \quad . \quad . \quad . \quad . \quad [14]$$

[1] In every case of refraction through a lens, or a simple system of lenses, the real image is always positive, *inverted, and on the opposite side of the lens* to the source of light, and the virtual image is always negative, *erect, and situated on the same side* as the source.

which renders our calculations easier. We will therefore consider D to represent the power of the lens, p and p' as the powers represented by the conjugate distances a and b, which are at once found by dividing 100 or 40 by the distances a or b, according as they are expressed in centimetres or inches.

Example.—Suppose the object be 80 cm. from a lens having a positive focal length of 20 cm., where will the image be situated?

Here $D = \frac{100}{20}$ or 5, and $p = \frac{100}{80}$ or 1,25.
Since $D = p + p', p = D - p' = 5 - 1{,}25 = 3{,}75$

which is the power left after the combat between the lens and the wave front. The distance of the image from the lens is therefore

$$\frac{100}{3{,}75} = 26\tfrac{2}{3} \text{ cm.}$$

Suppose the object is 20 in., and the image 5 in., from the lens, what is the focal length of the lens?

$$D = p + p' = 2 + 8 = 10, \textit{ i.e. } F = \tfrac{40}{10}, \text{ or } 4 \text{ in.}$$

Again, the focal length is 10 in., the object is 8 in., from the lens, where will the image be?

Taking $D = p + p'$ as before, $p = 4 - 5 = -1$. The negative sign shows us that the image will be on the same side as the object. It is therefore virtual, erect, and negative.

Suppose the lens is equi-convex (which is the case when both surfaces have the same curvature) and $r_1 = r_2 = 50$ cm., the refractive index of the glass being 1,5: what will the focal length be?

$$\frac{1}{F} = (\mu - 1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right) = 0{,}5 \times \left(\frac{1}{50} + \frac{1}{50}\right) = \frac{1}{50}\text{cm., } \textit{i.e. } F = r$$

or $D = (\mu - 1)(p + p') = 0{,}5 \times (2 + 2) = 2$, or 50 cm. as before.

From this we learn that in any equi-convex lens the focal length is the same as the radius of curvature.

Another example: A meniscus lens has $r_1 = 25$ cm. and $r_2 = -5$ cm. What is its focal length?

$$D = 0{,}5 \times (4 - 20) = -8, \text{ or } F = 12{,}5 \text{ cm., and negative.}$$

And if we could afford the space it could easily be shown that this principle will hold true for any number of lenses of any thickness and of any form, however complicated, only of

course we shall have to introduce a few more factors into the equation. The following question shows how simple a calculation for thin lenses becomes when made by the dioptric method. It can be worked on the thumb-nail.

Example.—Four thin lenses are placed in contact side to side along a common axis: (1) is a plano-concave of 4D; (2) a positive meniscus of radii + 2 in. and − 5 in. respectively ($\mu = 1{,}5$); (3) a biconvex of 50 cm. focus; and (4) a biconcave of $33\frac{1}{3}$ cm. focal length. What is the focal length of the combination? Here

$$F(1) = -4D;$$
$$F(2) = (\mu - 1)(p - p') = 0{,}5 \times (20 - 8) = 6D;$$
$$F(3) = 2D;$$
$$\text{and } F(4) = -3D.$$

Then − 4D + 6D + 2D − 3D = + 1D. The combination will therefore have a positive focal length of 100 cm., and can project a real inverted image.

§ 21. **Graphic Construction of the Image produced by a Thin Lens.**—First let us take the case of an infinitely thin

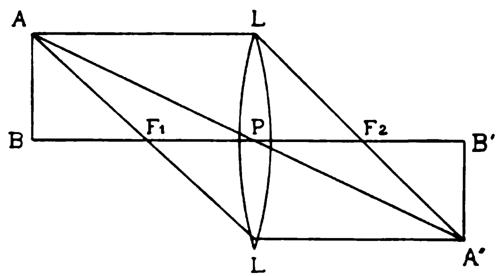


FIG. 43.

positive lens, by which we understand a lens so thin that the interval between the surfaces may be neglected.

Let L be such a lens (Fig. 43). AB a vertical object on the axis BB′, F_1 and F_2 the anterior and posterior principal foci of the lens. It is required to construct the image. Since B is on the principal axis, its image, B′, must likewise be somewhere on the axis. From A draw a line through P, the centre of the lens. Then, according to a well-known optical law, the ray will, if prolonged, pass through the image, which is the conjugate of A. From A draw a second line through the anterior focus F_1,

and such a ray when it is prolonged will, after refraction, pass in a direction parallel to the principal axis, and will meet the other ray from A at the conjugate focus A′. From A draw a third line, AL, parallel to the axis. On refraction it will pass through the posterior focus F_2, and if prolonged will meet the conjugate focus at A′. From A′ draw a line A′B′ parallel to AB.

Then B′A′ is the image of AB, since the intersection of any two of the above-mentioned lines drawn from A will define the position of an image point.

§ 22. **Graphic Construction of the Image produced by a Thick Lens.**—The focal length of an objective is often thought to be the distance between the back of the lens and the image on the focussing screen, when the object is a distant one. This is sometimes called the back focus (F_B), and is useful to know, but it is never the true focal length except in the solitary instance of a plano-convex lens placed with the flat side facing the object. In the case of all other lenses, or systems of lenses, the point from which the focal length has to be measured lies either between the components, as occurs in symmetrical lenses when the elements are placed close together, inside the lens as obtains in a biconvex lens, or lastly, outside the system altogether, as we find to be the case in all deep meniscus lenses, in many forms of cemented combinations, in symmetrical lenses placed at some distance apart, and, most important of all, in telephoto lenses. In this last case the point from which the focus has to be measured lies a long way (often many inches or even a foot or more) in front of the lens, a property which is very convenient since you can use a long focus lens with a short camera. It is, therefore, very important for the photographer who wishes to master his lens to find out the why and wherefore of this, and to know from what point to measure the focal length.

§ 23. **The Gauss Points and Planes.**—Our knowledge of the real course of rays through a system of lenses is due to three mathematicians who flourished during the first half of the nineteenth century—Moebius,[1] Gauss,[2] and Bessel.[3] A little

[1] Moebius, "Die Haupteigenschaften eines Systems von Linsengläsern," Gesam. Werke, Bd. IV., p. 479. 1829.

[2] Gauss, "Dioptr. Untersuchungen," Gesam. Werke, Bd. V., p. 245. 1840.

[3] Bessel, "Die Grundformeln der Dioptrik. Astronom. Nachr," Bd. 18. 1840.

later Moser[1] and Listing[2] completed the work. These five men formed the groundwork on which our knowledge of image formation is founded.

Moebius and Gauss found that for every lens or system of lenses, however complicated, provided they were arranged along a common axis, four cardinal or characteristic points, each situated in a plane at right angles to the axis, could be determined, and when these points were once known, the rays could be traced through the entire system, and their subsequent course ascertained. By this means the calculation for a number of symmetrically placed lenses was greatly simplified. Gauss only considered the case of lenses surrounded by air, as they naturally would be in nearly all cases, but Listing, when investigating the eye, found it necessary to add two more points, which he called "nodal points," since the image was formed in a denser medium than the object, which made the anterior and posterior focal lengths unequal. In fact, the posterior focal length is equal to the anterior focal length multiplied by μ_r, or the relative index of the two media, *i.e.* $\frac{\mu_2}{\mu_1}$. From this, a little reflection will show that the closer the index of the second medium gets to that of the first, so the interval between the nodal points and the equivalent points will be reduced, until when the two media are the same, the principal and nodal points will coalesce and become identical.

Since all lenses used in photography (except in very rare cases) have air on both sides, we need not refer to Listing's nodal point again, unless we use it to signify the second principal point, as is often done.

Knowing Gauss' four points and the planes in which they lie, it is quite easy to construct the image of any object. These points are: 1. The anterior focus (first principal focus); 2. The posterior focus (second principal focus); 3. Anterior or first principal point; 4. Posterior or second principal point.

In order to trace the course of rays through a compound system we can establish these four points for each element separately, and then we have the data for finding the four points for the combined system. In this latter case it is usual to call the principal points equivalent points, so that for a compound system we have two focal points and two equivalent

[1] Moser, "Ueber das Auge." Doves Repertorium. 1844.
[2] Listing, "Beitrag zur Physiol. Optik." 1845 and 1851.

points, so that, when located, we can readily trace the rays from any point on the object through the lens system to its corresponding image point.

All rays proceeding from an object are called incident rays, and all rays when they have passed through the lenses are termed emergent rays.

Since in all systems of lenses in air the two principal focal lengths are the same, it makes no difference to the focal length whether you turn the lens round (back to front) in the camera. Hence it follows that since the focal length in either direction is the same, the size of the image remains unaltered. And this holds true for any combination of lenses, so that if you turn a telephoto lens round with the positive lens nearest the camera, the magnification of the image will still remain unchanged, although the screen must be racked back a considerable distance, and the field projected will be smaller.

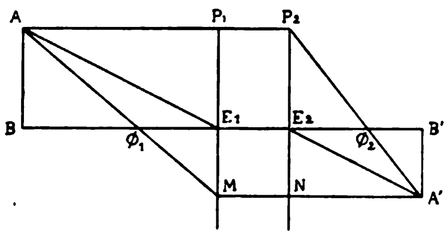


FIG. 44.—Diagram showing Gauss' points and planes.

The definition of Gauss' points and planes is as follows:—

The first principal focus, F_1 or ϕ_1 (Fig. 44), is the point to which a beam of rays parallel to the axis converge when they proceed from the image side of the lens system.

The second principal focus, F_2 or ϕ_2, is the point to which the rays of a beam of light parallel to the axis converge when they proceed from the object side of the lens system.

The first and second focal planes are imaginary planes passing through the focal points at right angles to the principal axis. They have the same property as those of a single refracting surface. The rays proceeding from any point in the first focal plane run parallel to each other after refraction, and to the secondary axes. Conversely, the rays that were parallel before refraction come to a focus on the second focal plane.

The first principal plane, P_1 (or first equivalent plane, E_1), is an imaginary plane placed at right angles to the principal axis,

and the first principal point is the point at which the axis cuts the plane.

The second principal plane, P_2 (or second equivalent plane, E_2), is a similar plane parallel to the first, and the second principal point is on the axis where it cuts the plane.

These two planes, which may be considered with their equivalent points, have the following properties:—

1. Any point on the first plane has its corresponding point on the second plane, and they are both equidistant from the axis and on the same side of it.

2. The two planes are conjugate to each other, and every incident ray which proceeds towards a point in the first plane will, after passing through the system, emerge as if it came from the corresponding point in the second equivalent plane.

3. Any ray directed towards the first equivalent point will, after passing through the system, emerge from the second equivalent point, or, at least, will appear to come from that point, and its direction after refraction will be parallel to the incident ray.

The two principal planes are therefore conjugate images of each other, having the same size and direction. In other words, they are planes of unit virtual magnification.

By making use of these properties we can readily construct the course of rays through any system. It will be found that the rays take exactly the same path as was shown in the case of a thin lens, *except that the rays appear to be transferred bodily from one plane to the other* (see Fig. 44).

The importance of these planes lies in the fact that the anterior focal length is measured from the first, and the posterior focal length from the second principal plane, or, more exactly, from the second principal point, and, therefore, $E_1\phi_1 = E_2\phi_2$. These planes are not only at all possible distances apart, but in compound systems they are very frequently crossed, *i.e.* the second plane will often be found on the object side of the first plane, but even in these cases the two focal lengths are the same.

Let DE_1M, FE_2N (Fig. 45) be the first and second equivalent planes; E_1, E_2 the equivalent points. AB = object, $B'A'$ the image, ϕ_1, ϕ_2 the two principal foci of the lens.

From the object-point A draw the incident ray AE_1. The ray will be refracted on entering the lens at G, and will pass in a straight line to H. Then HA' parallel to AG will be the

course of the refracted ray after leaving the lens. This ray directed towards E_1 appears, after refraction, to proceed from E_2. From A draw AD parallel to the axis. It will meet the lens at C and be refracted, but may be traced to D. The refracted ray will take the path $FK\phi_2A'$; the distance of F from the principal axis in the plane of E_2 being equal to that of D in the plane of E_1; the path of the ray within the lens being that of CK. Then D and F will be equidistant from the axis. Finally, from A draw a line through the anterior principal focus ϕ_1 and produce it to M. It will be refracted at the point where it meets the lens, and after refraction at the second surface will take the course NA′ parallel to the principal axis, so that A′ will be the conjugate image of A, and B′A′ will be the image of AB.

In the same way we can construct a virtual image. This is

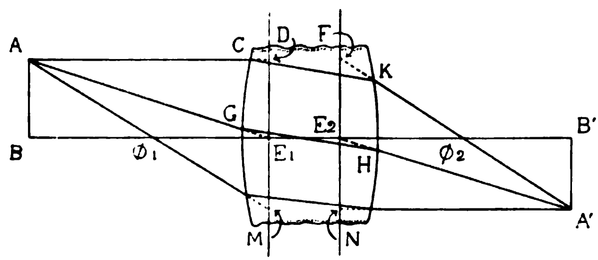


Fig. 45.—Graphic construction showing how a positive image is produced by a thick lens

formed by a negative lens in every case, and by a positive lens whenever the object is nearer the lens than the principal focus, which we see must be the case from our formula: $D = p + p'$ whenever p has more power than D. Let XY (Fig. 46) be the axis, E_1, E_2 the two equivalent points on the two planes P, P′. AB the object. Draw a line from A to E_1, cutting the axis at the equivalent point E_1. Then the refracted ray will appear to start from E_2 in the direction E_2H, parallel to AE_1. From A draw AC parallel to the axis. From D, a point on the second plane and at the same distance as C from the axis, draw DG, passing through F_2. Prolong the diverging lines E_2H and DG backwards, and they must meet at A′ on the object side. The point A′ where the two lines meet will be the image of A. In the same way the image of B can be found. Then A′B′ will be the geometrical image of AB. Since A′ is on the same side of the axis as A, the image is erect and virtual.

The calculations necessary to trace the course of rays through several lenses would be exceedingly complicated, if a separate calculation had to be made for each surface in turn; but by means of the Gauss method, the position of the conjugate points and planes of object and image can be definitely fixed, no matter how many lenses and refracting surfaces intervene, provided all the lenses are optically centred on a common axis.

The interval between E_1 and E_2 (or P_1 and P_2) is known as the optical interval or equivalent thickness of the lens, while the distance between F_1 and E_1, and F_2 and E_2 denote the true or equivalent focal distance of the lens, or lens system. The distance between F_2 and the posterior pole of the back lens is termed the back focus (F_B). Except in symmetrical lenses,

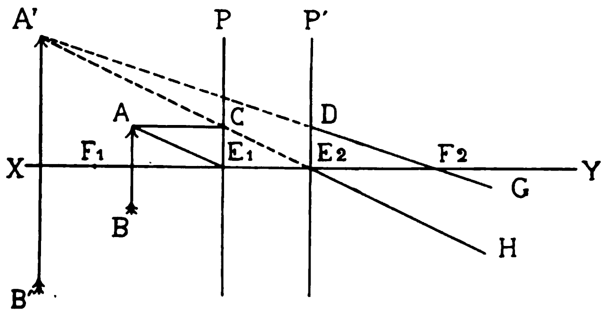


FIG. 46.—Graphic construction showing how a negative image is produced by a thick lens.

the distances between F_1 and the front lens, and F_2 and the back lens are never the same, although the distances E_1F_1 and E_2F_2, which are the true focal lengths, are invariably equal.

When the position of the equivalent planes in a system of lenses is examined, it will be found that in some cases the position of the planes is reversed or crossed, *i.e.* E_2 is to be found nearest the object, and E_1 nearest the image; but E_1 is always measured backwards from the front lens, and E_2 is always measured forwards from the back lens, except in the case of a periscopic or telephoto combination, in which case one of the equivalent points is measured negatively, *i.e.* in the opposite direction to that just mentioned.

If the focal lengths (F_1 and F_2) of two thin lenses are

known, the position of the equivalent points of the combination can readily be found from the formulæ

$$E_1 = \frac{F_1 d}{F_1 + F_2 - d} \text{ and } E_2 = \frac{F_2 d}{F_1 + F_2 - d} \qquad [15]$$

in which d = distance of separation between the two lenses.

An example will illustrate these formulæ. Let the focal length of the convex lens $L_1 = 6$ in., and that of the convex lens $L_2 = 9$ in. The two being separated by 2 in. (Fig. 47).

Then $\quad E_1 = \frac{6 \times 2}{6 + 9 - 2} = \frac{12}{13}$ in. behind the front lens L_1

$$E_2 = \frac{9 \times 2}{6 + 9 - 2} = 1\frac{5}{13} \text{ in. in front of } L_2.$$

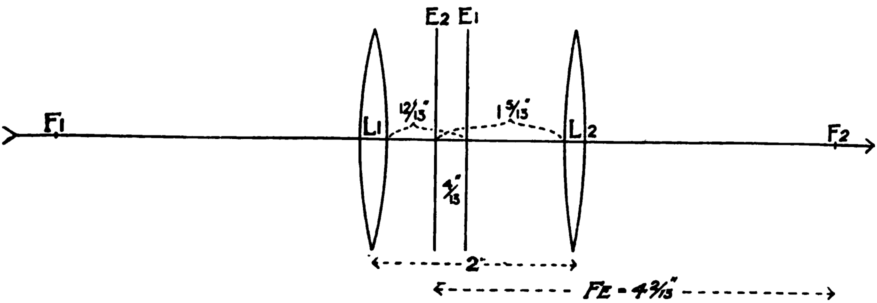


Fig. 47.

To find the equivalent focal length of the combination we have the formula

$$F_E = \frac{F_1 F_2}{F_1 + F_2 - d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [16]$$

in this case $\quad F_E = \frac{6 \times 9}{6 + 9 - 2} = \frac{54}{13} = 4\frac{2}{13}$ in.

which is the distance between F_1 and E_1 or F_2 and E_2.

As the lenses are separated 2 in., while E_1 is $\frac{12}{13}$ in. behind the front lens L_1, and E_2 is $1\frac{5}{13}$ in. in front of the back lens L_2, the two planes are crossed by an amount $= 2 - (1\frac{5}{13} + \frac{12}{13}) = \frac{4}{13}$ in., as is shown in Fig. 47.

Let us now consider the position of the equivalent planes when a positive and a negative lens are separated. The positive element being in front, as in an ordinary telephoto lens.

From [15] we have

$$E_1 = \frac{F_1 d}{F_1 - F_2 - d} \qquad E_2 = \frac{F_2 d}{F_1 - F_2 - d}$$

and from [16] $$F_E = \frac{F_1 \times F_2}{F_1 + F_2 - d}$$

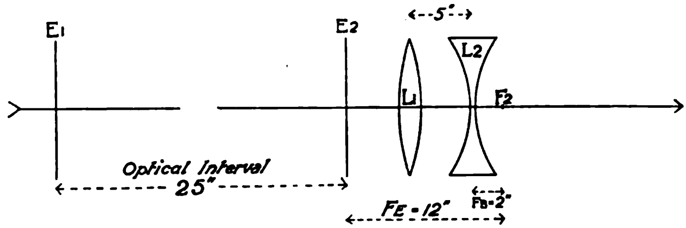


FIG. 48.—Gauss' planes of a positive and negative lens. The convex lens facing the light.

Example.—Let $L_1 = 6$ in. focal length, $L_2 = -2$ in., and $d = 5$ in.; then we get

$$E_1 = \frac{6 \times 5}{6 - 2 - 5} = \frac{30}{-1}$$

or 30 in. in front of L_1, since the distance is negative and is therefore measured towards the object (Fig. 48).

$$E_2 = \frac{-2 \times 5}{6 - 2 - 5} = \frac{-10}{-1}$$

or 10 in. in front of L_2 and 5 in. in front of L_1, since the distance has a positive value and is therefore measured towards

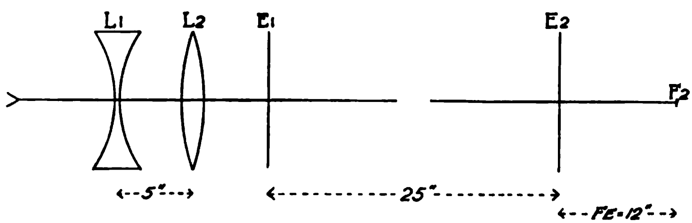


FIG. 49.—Gauss' planes of a positive and negative lens. Concave lens facing the light.

the object. Hence the distance between E_1 and $E_2 = 30 - 5$ or 25 in.

Lastly, F_E, or equivalent focal length

$$= \frac{6 \times -2}{6-2-5} = \frac{-12}{-1}, \text{ or 12 in. and positive,}$$

consequently F_E is 12 – 10 or 2 in. behind L_2.

If we turn the telephoto lens round so that the negative lens is in front, we have the condition of things found in the Adon lens. The two planes E_1 and E_2 will now be behind the combination (Fig. 49).

Then we get $$E_1 = \frac{-2 \times 5}{-2+6-5} = \frac{-10}{-1}$$

and $$E_2 = \frac{6 \times 5}{-2+6-5} = \frac{30}{-1}$$

E_1 will now be 10 in. behind, *i.e.* to the right of L_1, or 5 in. behind L_2 since it is positive.

E_2 will be 30 in. behind L_2, and F_E 12 in. to the right of E_2, or 42 in. (!) behind L_2. Since, however, F_E = 12 in. as before, the magnification remains unaltered, although the circle on the screen will be greatly diminished. Of course, such a distance would not occur in practice. The optical interval will be the same as before.

If both lenses have the same focal length, the lens assumes the form of a Beck-Steinheil unifocal (Fig. 50).

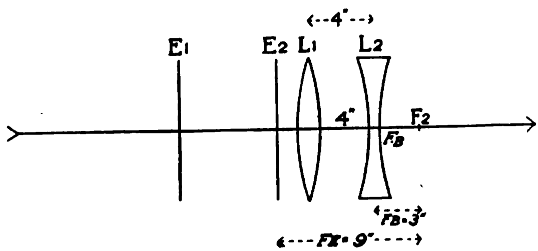


FIG. 50.

Example.—Let each lens have a focal length of 6 in., and suppose d = 4 in. Then

$$E_1 = \frac{6 \times 4}{6-6-4} = \frac{24}{-4} = -6 \text{ in.}$$

the negative sign showing that it must lie to the left of L_1, and

$$E_2 = \frac{-6 \times 4}{6-6-4} = \frac{-24}{-4} = 6 \text{ in.}$$

the positive sign showing that it must also lie 6 in. to the left of L_2. Also

$$F_E = \frac{-6 \times 6}{6 - 6 - 4} = 9 \text{ in.}$$

Hence $F_B = 9 - 6$, or 3 in. to the right of L_2.

§ 24. **Examples showing how the Gauss Method can be practically applied to Lenses of Various Forms when the Thickness of the Lenses is considered.**

Let P_1 = first principal point
P_2 = second principal point
e_1 = distance of P_1 from the anterior pole
e_2 = distance of P_2 from the posterior pole
ϕ_1 = anterior focus
$\phi_1 P_1 = F_1$ = anterior focal distance
ϕ_2 = posterior focus
$\phi_2 P_2 = F_2$ = posterior focal distance
r_1 = radius of first surface
r_2 = radius of second surface
t = thickness of the lens
$K_1 = \phi_1 r_1$, distance of front focus from the lens
$K_2 = \phi_2 r_2$, distance of back focus from the lens
$N = \mu r_1 + \mu r_2 - t(\mu - 1)$.

What we have to determine are the positions of ϕ_1, ϕ_2 and P_1, P_2. All the others can be immediately obtained from these.

Biconvex Lens (Fig. 51):

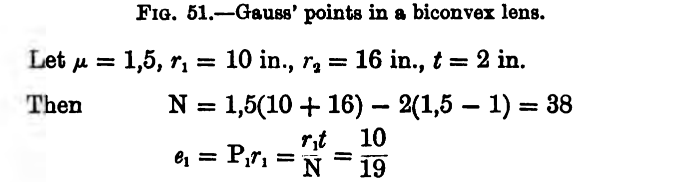


FIG. 51.—Gauss' points in a biconvex lens.

Let $\mu = 1{,}5$, $r_1 = 10$ in., $r_2 = 16$ in., $t = 2$ in.

Then $\qquad N = 1{,}5(10 + 16) - 2(1{,}5 - 1) = 38$

$$e_1 = P_1 r_1 = \frac{r_1 t}{N} = \frac{10}{19}$$

$$e_2 = P_2 r_2 = \frac{r_2 t}{N} = \frac{16}{19}$$

As they are positive, the distances must be measured from their respective poles, in the direction of the opposite surface. If either e_1 or e_2 were negative they would have to be measured in the opposite direction.

Since $t = 2$, the distance between P_1 and P_2

$$= 2 - \left(\frac{16}{19} + \frac{10}{19}\right) = \frac{12}{19}$$

The focal length F_1

$$= F_2 = \frac{\mu r_1 r_2}{(\mu - 1)N} = \frac{1{,}5 \times 160}{0{,}5 \times 38} = 12\tfrac{12}{19}$$

Since F = distance of ϕ from the pole $+ e$, we have a ready means of checking our calculation. Thus

$$K_1 = \frac{\mu r_1 r_2 - r_1 t(\mu - 1)}{(\mu - 1)N}$$

$$= \frac{1{,}5 \times 10 \times 16 - 10 \times 2 \times 0{,}5}{0{,}5 \times 38}$$

$$= \frac{230}{19} = 12\tfrac{2}{19}$$

But $$F_1 = K_1 + e_1 = 12\tfrac{2}{19} + \tfrac{10}{19} = 12\tfrac{12}{19}$$

Again $$K_2 = \frac{\mu r_1 r_2 - r_2 t(\mu - 1)}{(\mu - 1)N}$$

$$= \frac{1{,}5 \times 10 \times 16 - 16 \times 2 \times 0{,}5}{0{,}5 \times 38}$$

$$= \tfrac{224}{19} = 11\tfrac{15}{19}$$

But $$F_2 = K_2 + e_2 = 11\tfrac{15}{19} + \tfrac{16}{19} = 12\tfrac{12}{19}$$

From tbis it follows that $K_1 + e_1 = K_2 + e_2$, or $F_1 = F_2$

Biconcave Lens: Values as before.

Here r_1 and r_2 are negative.

$$N = \mu r_1 + \mu r_2 - t(\mu - 1) = -40$$

$$e_1 = \frac{r_1 t}{N} = \frac{-20}{-40} = +\frac{1}{2}$$

$$e_2 = \frac{r_2 t}{N} = \frac{-32}{-40} = +\frac{4}{5}$$

$$F_1 = F_2 = \frac{\mu r_1 r_2}{(\mu - 1)N} = -12$$

Here e_1 and e_2 are positive, and therefore must be measured inwards as in the last example.

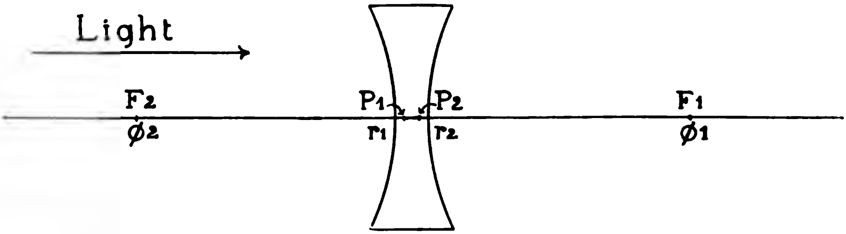


FIG. 52.

Plano-convex Lens.—Curvature towards the image (Fig. 53).

$$r_1 = \infty,[1] \quad r_2 = 16, \; t = 2$$

$$N = \mu(r_1 + r_2) - t(\mu - 1) = \mu\infty$$

$$e_1 = \frac{r_1 t}{\mu\infty} = \frac{t\infty}{\mu\infty} = \frac{t}{\mu} = \frac{2}{1,5} = \frac{4}{3}$$

$$e_2 = \frac{r_2 t}{\mu\infty} = \frac{16 \times 2}{1,5\infty} = 0$$

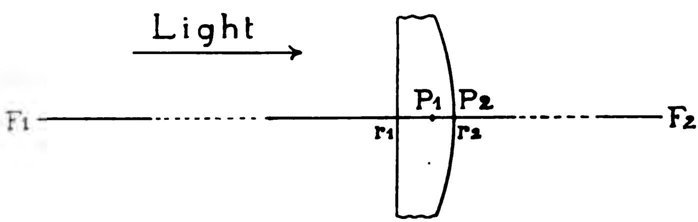


FIG. 53.

Therefore P_2 lies on the axis at the pole of r_2, and P_1 $1\frac{1}{3}$ from r_1.

$$F_1 = F_2 = \frac{\mu r_1 r_2}{(\mu - 1)N} = \frac{\mu r_2 \infty}{\mu(\mu - 1)\infty}$$

$$= \frac{\mu r_2}{\mu(\mu - 1)} = \frac{24}{0,75} = 32$$

Plano-convex turned round.—Curvature towards the object (Fig. 54).

$$r_1 = 16, \; r_2 = \infty, \; N = \mu\infty$$

$$e_1 = \frac{r_1 t}{\mu\infty} = \frac{16 \times 2}{\mu\infty} = 0$$

[1] Infinity is represented in mathematics by the symbol ∞.

Therefore P_1 lies on the axis at the pole of r_1.

$$e_2 = \frac{r_2t}{\mu\infty} = \frac{t\infty}{\mu\infty} = \frac{t}{\mu} = \frac{4}{3}$$

i.e. P_2 lies $\frac{2}{3}$ to the right of the pole of r_1. $F_1 = F_2 = 32$, as before.

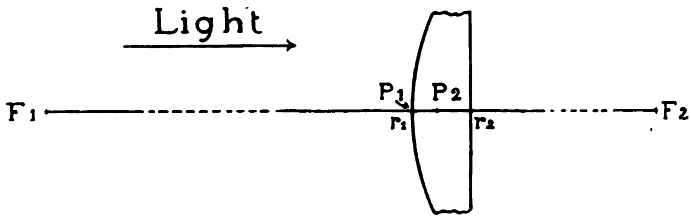


FIG. 54.

Positive Meniscus:

$$r_1 = 10, r_2 = -16, t = 2$$

$$N = \mu r_1 + \mu r_2 - t(\mu - 1) = 15 - 24 - 1 = -10$$

$$\therefore e_1 = \frac{r_1t}{N} = \frac{10 \times 2}{-10} = -2$$

$$e_2 = \frac{r_2t}{N} = \frac{-16 \times 2}{-10} = 3{,}2$$

$$F_1 = F_2 = \frac{\mu r_1 r_2}{(\mu - 1)N} = \frac{-240}{-5} = 48$$

Here e_1 is negative, and the distance of P_1 is therefore 2 in. on the left of r_1; but e_2 is positive, and P_2 is therefore measured

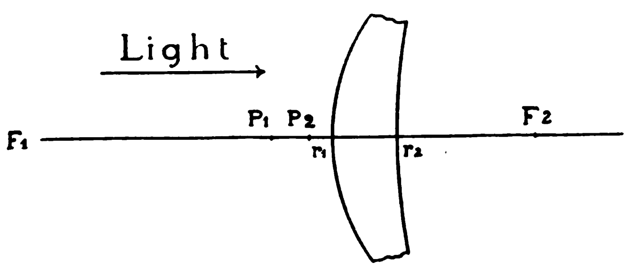


FIG. 55.

3,2 in. to the left of r_2, or 1,2 in. to the left of r_1. The principal points are therefore outside the lens.

No-Curvature Lens.—This is dealt with elsewhere (p. 118), but it is interesting to find out the Gauss points (Fig. 56).

In this lens the two radii have the same curvature but

opposite signs, *i.e.* $r_1 = r_2$, so that the distance between the poles is the same as the distance between the two centres, C_1 and C_2, and the resultant curvature is nil, since the second curve neutralizes the effect of the first. It is therefore called a no-curvature or nil-curvature lens (German, *Nulkrum mung Linse*).

$$r_1 = -r_2 = 10,\ t = 2,\ N = -1$$

$$e_1 = \frac{r_1 t}{N} = \frac{20}{-1} = -20$$

$$e_2 = \frac{-10 \times 2}{-1} = 20$$

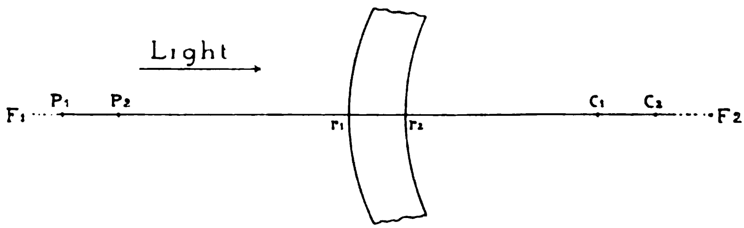


FIG. 56.—No-curvature lens.

Therefore P_1 being negative, it lies 20 to the left of r_1, and P_2 lies 20 to the left of r_2, being positive.

$$F = \frac{1{,}5 \times 10 \times -10}{0{,}5 \times -1} = 300, \text{ and positive}$$

The power of this lens depends upon its thickness, for if t vanishes F becomes infinite. This form of lens is closely imitated in nearly all astigmats and anastigmats, each half being of nearly equal thickness throughout. By this means the aberrations are reduced to a minimum.

Concentric Lens (Fig. 57).—In this form both curves are

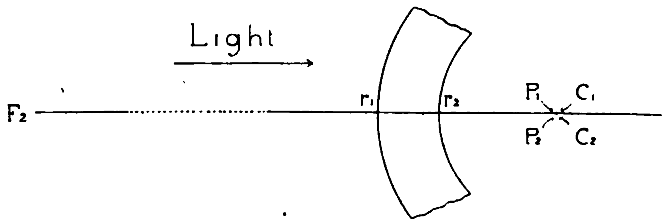


FIG. 57.—Concentric lens.

struck from the same centre. This is the characteristic of the Ross lens.

Suppose $t = 2$, $r_1 = 3$, $r_2 = -1$

Then
$$N = 1{,}5(3 - 1) - 1 = 2$$

$$e_1 = \frac{r_1 t}{N} = \frac{3 \times 2}{2} = 3$$

$$e_2 = \frac{r_2 t}{N} = \frac{-1 \times 2}{2} = -1$$

Therefore P_1 and P_2 both lie at the centre of curvature common to both curves.

$$F_2 = \frac{\mu r_1 r_2}{(\mu - 1)N} = \frac{1{,}5 \times 3 \times -1}{1} = -4{,}5$$

Combined Lenses.—Lastly, let us apply the Gauss method to two thick lenses of different indices separated by an air space (Fig. 58).

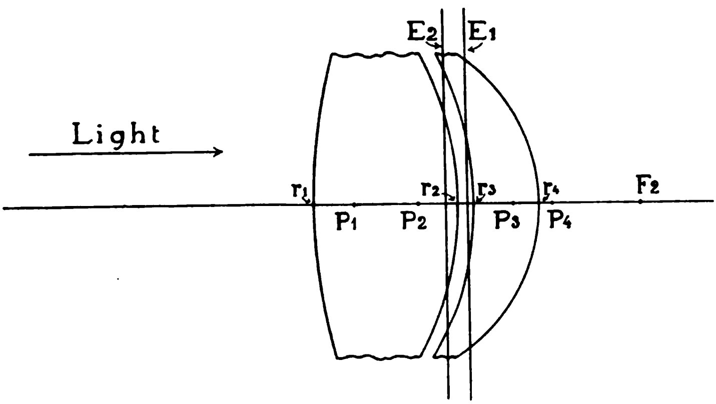


FIG. 58.

First Lens:

$\mu = 1{,}5$, $t = 3$, $r_1 = 6$, $r_2 = 4$

$$N = \mu r_1 + \mu r_2 - t(\mu - 1) = 1{,}5(6 + 4) - (3 \times 0{,}5) = 13{,}5$$

$$F_1 = F_2 = \frac{\mu r_1 r_2}{(\mu - 1)N} = \frac{1{,}5 \times 6 \times 4}{6{,}75} = \frac{36}{6{,}75} = 5{,}33$$

$$P_1 = \frac{r_1 t}{N} = \frac{18}{13{,}5} = 1{,}33$$

$$P_2 = \frac{r_2 t}{N} = \frac{12}{13{,}5} = 0{,}888$$

Second Lens:

$$N = 1,6(-4+2) - 0,6 = -3,8$$

$$F_3 = F_4 = \frac{1,6 \times -8}{0,6 \times -3,8} = \frac{-12,8}{-2,28} = +5,614$$

$$P_3 = \frac{r_3 t}{N} = \frac{-4}{-3,8} = 1,05$$

$$P_4 = \frac{r_4 t}{N} = \frac{2}{-3,8} = 0,525$$

The equivalent points and the foci, F'_1 and F'_2, of the combined lenses can now be found.

Let d = distance between P_2 and $P_3 = 2$, *i.e.* the interval between the second principal point of the first lens and the first principal point of the second lens.

The lenses will be very close together, since

$$2 - (0,888 + 1,05) = 2 - 1,894 = 0,106 \text{ in.}$$

$$F'_1 = F'_2 = \frac{F'_1 F'_2}{F'_1 \text{ and } F'_2 - d}$$

$$= \frac{F'_1 F'_2}{N} = \frac{5,33 \times 5,614}{5,33 + 5,614 - 2}$$

$$= \frac{29,939}{8,947} = 3,35 \text{ in.}$$

Therefore F'_1 is 3,35 in. to the left of P_1, and F'_2 is 3,35 in. to the right of P_2.

$$E_1 = \frac{5,33 \times 2}{8,947} = 1,19 \text{ in. to the right of } P_2$$

$$E_2 = \frac{5,614 \times 2}{8,947} = 1,25 \text{ in. to the left of } P_3$$

Therefore the interval between E_1 and E_2

$$= 2 - (1,19 + 1,25) = -0,44$$

which, being subtracted from a negative quantity, shows us that the equivalent points are crossed.

In the same way, by means of the Gauss points and planes, we can trace the course of rays through any number of centered lenses.

§ 25. **Chromatic Aberration and the Achromatizing of Lenses.**—When a beam of sunlight is admitted through a narrow slit and allowed to fall on one of the faces of a glass

prism, the emergent beam no longer consists of white light, but is spread out into a band consisting of the spectrum colours: violet, blue, green, yellow, orange, and red, the latter being nearest the apex, the violet on the side directed to the base. This is due to the unequal refraction of the rays, the violet being the most, the red the least, refracted. The narrower the slit the purer and better defined will be the colours. If, now, a similar prism of the same thickness and index be placed in contact with this prism and turned round base to apex, the colours will immediately disappear, and the issuing beam will consist of white light. These facts were discovered by Sir Isaac Newton, and first recorded in his "Optiks" in the year 1704. At that time the spectrum thus seen on a screen was supposed to comprise the entire spectrum, but we now know that the spectrum thus perceived by the eye only forms a very small portion of the entire spectrum, which extends in both directions beyond its visible limits; indeed, a considerable portion of the invisible spectrum beyond the violet end will be found to affect the photographic plate. On the other hand, the red and orange part of the spectrum, though extremely brilliant to the eye, will hardly affect an ordinary photographic film at all, but can readily be made to do so if the plate be dyed with erythrosin or eosin, which increases the absorptive power of the film for the red end of the spectrum. Newton thought that the dispersion of a lens, or prism, was always in proportion to its refractive power, so that if two prisms of different refractive indices placed base to apex, or a convex and concave lens were combined, one could only overcome the dispersion by neutralizing the refractive powers of the prisms, or lenses. If this were true, a real image free from colour would be impossible. In fact, Newton asserted that refraction could not be obtained without colour.[1] It was for this reason that he abandoned the construction of refracting telescopes, and turned his attention to reflectors, since when light is reflected all the rays are reflected equally, and there is consequently no chromatic aberration at all. Such was the authority of Newton that no serious attempt to improve the manufacture of lenses was made during his lifetime. The discovery of the method of achromatizing lenses was first made

[1] "Optiks, or a Treatise of the Reflections, Refractions, Inflections, and Colours of Light," book i., part ii., prop. ii., theor. 2, and prop. iii. Published by Sam. Smith and Benj. Walford, London, 1704.

by Chester Moor Hall, an Essex gentleman who, however, failed to recognize the importance of his discovery, and it was left to Dolland a few years afterwards to rediscover and manufacture such lenses commercially. We have in the Ophthalmoscope an exactly parallel case. Babbage invented the Ophthalmoscope, but cast it aside as unimportant. Helmholtz, four years afterwards, reinvented it, and gave it to the world.

Newton's mistake lay in supposing that the ratio between dispersion and refraction (deviation of the rays) was identical for all kinds of glass. Dolland (the founder of the well-known firm of opticians in London) was led to doubt this by analogy from the human eye. He argued that since we do not see coloured fringes when looking at objects against the sky with the naked eye, it must be possible to construct lenses on the same lines. We know now that the eye is not perfectly achromatic, but, fortunately perhaps for optics, Dolland was unaware of this. He therefore made a series of trials with lenses ground from various kinds of glass, having not only different indices of refraction, but different dispersive powers. In this way he succeeded in combining a positive crown glass with a negative flint, so that the dispersion was neutralized, while some converging power was left over to produce an image. We shall presently show how this can be done.

§ 26. **Fraunhofer's Lines.**—If the sun's spectrum formed by a very narrow slit in front of a prism be examined, a large number of black lines will be noticed crossing the spectrum band. These are known as Fraunhofer's Lines, from their discoverer. He mapped out over 600 of them, and assigned to the most conspicuous ones the letters of the alphabet. The accompanying diagram shows the position of the most important of these lines in a typical specimen of crown and flint glass.

These lines are absolutely fixed, no matter what kind of glass or other material the prism is made of. Thus the potassium line A′ is always found in a certain position in the spectrum, viz. in the red, which corresponds to a wave length of 768,2$\mu\mu$; that of the hydrogen line C, in the red-orange, to a wave length of 656·3$\mu\mu$; that of the middle of the sodium line D, in the brightest part of the spectrum, to 589·3$\mu\mu$; while that of F and G, in the greenish blue and dark blue respectively, corresponding to wave lengths of 486·2$\mu\mu$ and 434·1$\mu\mu$.

These five lines are specially selected by glass manufacturers as standards by which they measure the dispersive values of

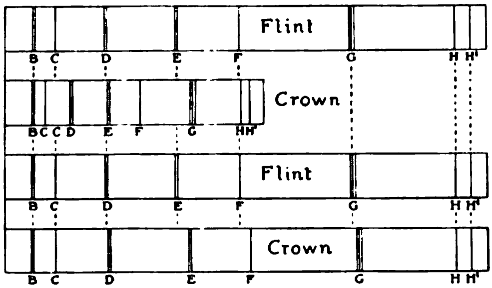


FIG. 59.

1. Spectrum lines of flint glass.
2. Narrow spectrum of crown glass.
3. Same as 1.
4. Spectrum of crown glass enlarged until the B and H lines coincide. The remaining lines do not correspond with those of the flint owing to irrationality of the spectrum.

their glasses, and they should be committed to memory, as they are repeatedly referred to in all books on lenses and prisms.

Letter	A	C	D	F	G
Position	Middle of the double line	—	Middle of the double line	—	—
Wave length	768·2$\mu\mu$	656·3	589·3	486·2	434·1
Colour	Red	Red-orange	Yellow	Greenish blue	Dark blue

§ 27. **Irrationality of the Spectrum.**—Although the lines are always fixed as regards their wave lengths, the deviation of different parts of the spectrum differs considerably for different kinds of glass. For example, if we enlarge the crown glass spectrum until the B and H lines coincide with the corresponding lines of the flint spectrum, we shall

notice that the intervening lines do not correspond, as is obvious from our diagram. So that, although it is always possible to grind two kinds of glass so that any two given lines can be made to correspond, one cannot combine the remaining lines of the spectrum. Thus we can so arrange a pair of prisms, or lenses, that either the C and H, F and C, or G and D lines will coincide and be brought to a common focus, but whichever lines we contrive to bring together, the remaining lines will not completely combine. This phenomenon is known as the "Irrationality of the Spectrum." Lenses so combined as to bring the foci of two colours together are called achromatic. Thus for purely visual purposes the F and C lines are usually brought together, while for photography the G and D lines are combined. Of course the F and H lines would really be more useful for this purpose, but then the visually bright C and D lines would be left out of focus and the photographer would focus wrongly. In certain cases, as in stellar photography for example, the object is always at the infinity point, so that the image plane can be fixed once for all by calculation or trial, and the objective improved by achromatizing it for these lines.

The spectrum which remains over after any two lines are approximated is called the secondary spectrum. This is only a feeble remnant of the original spectrum, since by uniting two lines wide apart you approximate all the others considerably. Still a narrow fringe of colour remains.

§ 28. **Apochromatic Lenses.**—In order to try and eliminate this secondary spectrum, Professor Abbe, in conjunction with the firm of Schott of Jena, made an elaborate series of experiments, with the result that glasses were cast having a very wide range between dispersion and refraction. By means of these glasses, together with certain transparent crystals, such as pebble and fluorite, Abbe succeeded in bringing *three* colours together, by which the secondary spectrum was almost completely eliminated. This can be done by first combining two lines together by means of a pair of glasses, and, having obtained an achromatic focus, he next selected a third glass by which a third line can be brought into harmony with the combined focus of the two lines. Such lenses are termed apochromatic, and are of great value for high power microscopy, colour photography, and process work. For example, the orange C line *b*, 563μ, or the orange-yellow lithium line, 610μ, may be combined with the green *b*, 517μ, and the blue-violet *g*, 423μ.

§ 29. **Mean Dispersion, Partial Dispersion, and Relative Dispersion.**—When the refractive index of any substance is given, it is understood to mean the amount of deviation that a ray corresponding to the D, or sodium, line undergoes when passing from air through the medium in question. It is written μ_D (or n_D). Similarly, a ray corresponding to the F line is expressed by μ_F (or n_F).

Mean Dispersion.—As the interval between C and F is the brightest part of the spectrum, it is extremely useful to know the amount of dispersion comprised by these limits. Thus a specimen of flint glass has a refractive index of 1,6306, *i.e.* $\mu_D = 1{,}6306$. For the C line, $\mu_C = 1{,}6254$, and for the F line, 1,6434. The middle, or mean, dispersion is therefore $\mu_F - \mu_C$, or $1{,}6434 - 1{,}6254 = 0{,}0180$.

Partial Dispersion.—It is also important, when picking out a suitable glass from the catalogue, to know the amount of dispersion between certain parts of the spectrum, especially between A and D, D and F, and F and G. These intervals represent the partial dispersion for these portions of the spectrum. Thus, in the above case, the partial dispersion between F and G $= 1{,}6554 - 1{,}6434 = 0{,}0120$, which is the interval required for photographic lenses, while C and F is the best interval for field-glasses.

Relative Dispersion.—Finally, it is necessary to find the ratio between the mean refractivity of the D ray, which is the same as the refractive index of the substance less one (or $\mu_D - 1$), and the partial dispersion for the two rays selected. Thus, in the above example

$$\mu_D - 1 = 0{,}6306 \text{ and } \mu_F - \mu_C = 0{,}0180.$$

This ratio is therefore represented by the equation

$$\omega = \frac{1}{\nu} = \frac{\mu_F - \mu_C}{\mu_D - 1}$$

which gives the value for the relative dispersion. The reciprocal of this value, or $\frac{\mu_D - 1}{\mu_F - \mu_C}$, is always represented by the Greek letter ν (Nu) or sometimes by $\frac{1}{\omega}$ (in English works). This symbol means that in a thin lens the interval between the focus of the C rays and that of the F rays is equal to the νth part of the D, or "standard," focus of the lens.

In the above glass $\nu = \frac{6306}{0180} = 35$. You have only to tell any good lens maker what the values for μ and ν are for any two glasses, and he will know at once whether they will achromatize nicely, and are likely to fulfil the sine condition and give a flat field.

§ 30. **Achromatizing of Lenses.**—The union of the various rays of the spectrum to form a common focus is an extremely difficult matter in photographic lenses, owing to the numerous requirements to be fulfilled. In an opera-glass or telescope the object subtends a relatively very small angle, and oblique rays play a correspondingly small part; but in a photographic lens a flat field extending over a very wide angle is required. Very oblique rays have to be calculated for, and not only must the lens be achromatized, but, in addition, the sine condition and, to a certain extent at any rate, the Petzval condition must be fulfilled, as well as the achromatic distances for the other aberrations.

Again, the optician must see that the images of the different colours not only fall on to the same plane, but are of the same magnitude; for you may achromatize a lens so that the images overlap but they may not be of the same size, or they may be of the same size and yet fall on different planes. Lastly, the achromatic distances for the other aberrations have to be adjusted.

These latter corrections, however, are refinements which very few makers of photographic lenses trouble themselves about, and hardly any opticians have the patience or knowledge to calculate them mathematically. We shall, therefore, content ourselves with learning how to achromatize a positive and negative lens for a bundle of rays parallel to the axis. If this is done properly, with due regard to the choice of the glasses and their curvatures, a lens may be made which is achromatic and will give excellent definition with F/7 or F/8 over a medium angle of say 50°. We will consider the achromatism of a pair of thin lenses in contact. Let f_1 be the focal length of the positive, f_2 that of the negative, element, and F that of the combination; then, from [6]

$$\frac{1}{F} = \frac{1}{f_1} - \frac{1}{f_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad [17]$$

or

$$F = \frac{f_1 f_2}{f_1 - f}$$

If we replace F by D the power in dioptries is then clearly

$$D = p - p'$$

or the power of the lens is equal to the power of the positive element less the power of the negative element.

In the above case it is clear that f_1 must be less than f_2, *i.e.* the power of f_1 (or p) must be greater than the power of f_2 (or p'), otherwise the focus will either be at ∞ or negative. For let $f_1 = f_2$,

then $$F = \frac{f_1 f_2}{0} = \infty$$

or $$D = p - p' = 0$$

$$\textit{i.e. } F = \infty \text{, as before.}$$

Secondly, let the power b be greater than a. Suppose $f_1 = 20$ in. and $f_2 = 5$ in.,

$$\textit{i.e. } p = \frac{40}{20} = 2 \text{ and } p' = \frac{40}{5} = 8$$

Then $$D = 2 - 8 = -6 \text{ or } F = -6\tfrac{2}{3}$$

and the focus is virtual and negative.

Therefore f_2 must have a greater focal length than f_1, or the power of p must be greater than that of p' to get a real image. Suppose $f_1 = 4, f_2 = 8$.

Then $$\frac{1}{F} = \frac{1}{4} - \frac{1}{8} = \frac{8-4}{32} \text{ or } \frac{1}{8} \text{ and } F = 8 \text{ in.}$$

or expressed in dioptries

$$D = 10 - 5 = 5 \text{ and } F = \frac{40}{5} \text{ or 8 in., as before.}$$

In this case the image will be real and positive.

§ 31. **Old Achromats.** — In order to give the positive element a short focus, and therefore a high power, one may either deepen the curves or else select a glass of higher index. Now, a positive lens of short focus combined with a negative lens of long focus can never give a flat field free from colour unless the spherical and chromatic aberrations in the two elements neutralize one another. With all the glasses which were cast up to the Jena epoch, it was impossible to find one with a high refractive index which did not carry with it a high dispersion. From the following table, containing a few samples of the old glasses, it is evident that as the refractive index gets

higher the dispersive power increases, and the ν value (being its reciprocal), of course, decreases.

Glass.	Refractive index μ_D.	Mean dispersion $\mu_F - \mu_C$.	$\frac{\mu_D - 1}{\mu_F - \mu_C} = \nu$.	Dispersive power $\frac{1}{\nu}$.
Silicate crown . .	1,5166	0,0085	60,9	0,0088
Hard crown . . .	1,5146	0,0091	56,5	0,0177
Light flint	1,5728	0,0138	41,5	0,024
Do.	1,5243	0,0204	25,7	0,039
Do.	1,5258	0,0207	14,7	0,068
Dense flint . . .	1,6236	0,0433	14,5	0,069

A few glasses of the Fraunhofer period.

Now, the chromatic interval, or distance, between the focus for different colours which gives rise to colour circles varies inversely as the focal length, so that the shorter the focus and the higher the power, the larger will be the chromatic circles. This caused the trouble, for when the optician used the old glasses he found that in proportion as he increased the power of his positive element, either by deepening the curves or selecting a higher index, he found the dispersive power mounting up as well, and, in addition, he could no longer get a sharp, flat image over a wide field. In fact, with the old glasses this was a physical impossibility, for the following simple reasons. In order to get an achromatic image having a perfectly flat field, it is necessary that

$$\frac{1}{\mu_1 f_1} + \frac{1}{\mu_2 f_2} = 0 \quad . \quad . \quad . \quad . \quad . \quad [18]$$

which may be written

$$\mu_1 f_1 = - \mu_2 f_2 \quad . \quad . \quad . \quad . \quad . \quad [19]$$

This shows that the two foci must have opposite signs, and further that, in order to balance the two sides of the equation, the element of *greater* focal length must have the *lower* refractive index, and, conversely, the lens of *shorter* focal length, and therefore of more power, must have the *higher* index.

Supposing f_1 were made equal to f_2, then, obviously, μ_1 must be equal to μ_2, and the combination would have no refracting power at all. On the other hand, if f_1 has less power (longer focus) than f_2, the resulting lens would give rise to a virtual image.

It is therefore obvious that the only solution of the difficulty was to produce glasses which combined high refractivity with low dispersion, and low refractivity with high dispersion, and this is exactly what was done at Schott's factory in Jena. Lenses made from these glasses are termed *new achromats*, in contradistinction to the *old achromats* of the Fraunhofer period.

We will work out one or two examples of each.

Let us, for example, select from among the "old" glasses a Hard crown, $\mu_1 = 1{,}5146$ and $\nu_1 = 56{,}5$, and pair it with a Light flint, $\mu_2 = 1{,}5728$ and $\nu_1 = 41{,}5$.

Now, the simplest way of working out our problem is to calculate the values for a focal length of 1, and then multiply it by any focal length we require. This will give us the required focal length for each of the two elements, or, having obtained our ratio between the two by making use of formula [**17**], $\frac{1}{F} = \frac{1}{f} - \frac{1}{f_2}$, all we have to do is to multiply each of the numbers by such a value that when the negative power is subtracted from the positive power we shall have the required positive power or focal length remaining over.

Thus
$$f_1 = \frac{\nu_1 - \nu_2}{\nu_1} \text{ and } f_2 = \frac{\nu_1 - \nu_2}{\nu_2} \quad . \quad . \quad . \quad [\mathbf{20}]$$

or, in dioptries, which make the calculation still simpler,

$$D_1 = \frac{\nu_1}{\nu_1 - \nu_2} \text{ and } D_2 = \frac{\nu_2}{\nu_1 - \nu_2} \quad . \quad . \quad [\mathbf{21}]$$

In the above selection $\nu_1 = 56{,}5$ and $\nu_2 = 41{,}5$.

If we therefore select powers proportional to these values, we shall obtain a resulting lens having a power proportional to the difference, which in this case $= 56{,}5 - 41{,}5 = 15$.

Suppose we require a 4-in. focus lens = 10D, all we have to do is to multiply $\frac{\nu_1}{\nu_1 - \nu_2}$ by 10, and we get $\frac{10 \times 56{,}5}{15} = 37{,}66\text{D}$ for the crown and $\frac{10 \times 41{,}5}{15} = -27{,}66\text{D}$ for the flint.

By combining these two values we obtain

$$37{,}66 - 27{,}66 = 10\text{D}$$

or 4 in., the lens required.

If we prefer to work out the focal lengths in inches or centimetres instead of dioptries, then $F_1 = \frac{\nu_1 - \nu_2}{\nu_1}$ and $F_2 = \frac{\nu_1 - \nu_2}{\nu_2}$ will give the same result. Thus

$$F_1 = \frac{\nu_1 - \nu_2}{\nu_1} \times 10 = \frac{150}{56{,}5} = 2{,}66 \text{ cm.}$$

which is the same as 37,66D, and $F_2 = -$ 3,61 cm. $=$ $-$ 27,66D.

The above calculation provides a lens which has a positive focal length and is achromatic, but it does not yield a flat image, nor is it entirely free from spherical aberration. In order to be free from curvature of field it must satisfy the equation

$$\frac{1}{\mu_1 f_1} + \frac{1}{\mu_2 f_2} = 0 \text{ or } \mu_1 f_1 = -\mu_2 f_2$$

But we have just shown that F_2 is greater than F_1, as it must be to give a positive focus. Therefore, to satisfy this last equation, μ_2 must be less than μ_1, which is a value which cannot be obtained from the old glasses.

§ 32. **New Achromats.**—We append a few select modern glasses from Schott's catalogue specially adapted for photographic and apochromatic lenses. In this case, instead of $\mu_F - \mu_C$ it is best to use $\mu_G - \mu_D$, since the G line is well in the blue-violet, which is the most sensitive part of the spectrum for the plate, and D is the brightest part for the eye. The ν for this partial dispersion is indicated by a dash, $\bar{\nu}$.

Mark.	Character.	Refractive index μ_D.	$\mu_G - \mu_D$.	$\bar{\nu}$
0.20	Silicate crown	1,5019	0,0107	46,9
0.114	Soft crown	1,5151	0,0116	44,3
0.60	Hard crown	1,5179	0,0109	47,4
0.726	Extra light flint.	1,5398	0,014	36,5
0.202	Heavy barium silicate crown .	1,604	0,0140	43,2
0.1209	Dense baryta crown . . .	1,6112	0,0136	44,8
0.103	Dense flint	1,6202	0,0226	27,4

Selected specimens of Jena glass from Schott's Catalogue, suitable for pairing.

Let us take 0,60, $\bar{\nu} = 47{,}4$ and $\mu_1 = 1{,}5179$, and combine with 0,103, $\bar{\nu}_2 = 27{,}4$, and $\mu_2 = 1{,}6202$ to make a quarter-plate achromat of 5-in. focus or 8D.

$$D_1 = \frac{1}{f_1} = \frac{\nu_1}{\nu_1 - \nu_2} = \frac{47,4}{20} = +\,2,37 \times 8 = 18,96\text{D or } 5,26 \text{ cm.}$$

$$D_2 = \frac{1}{f_2} = \frac{\nu_2}{\nu_1 - \nu_2} = \frac{27,4}{20} = -\,1,37 \times 8 = -\,10,96\text{D or } 9,1 \text{ cm.}$$

These may be worked as plano-spheres with the flat sides cemented, and the combined focus will = 18,96 – 10,96, or 8D.

We must now find out what curves to give to the lenses, since the chromatism is related to the focal lengths of the lenses, but the spherical aberration to the curves. As our two lenses are cemented together, we have only three curves to consider. Let the lenses be of the following shape (Fig. 60), the positive being biconvex, the negative plano-concave.

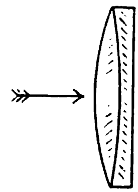


FIG. 60.

Let r_1 and r_2 be the radii of the convex, and r_3 and r_4 those of the concave lens.

Since $$D_1 = \frac{1}{f_1} = 2,37, \text{ and } D_2 = \frac{1}{f_2} = -\,1,37$$

we have $$\frac{1}{f_1} = (\mu_1 - 1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right) = 2,37$$

and $$\frac{1}{f_2} = (\mu_2 - 1)\left(\frac{1}{r_3} + \frac{1}{r_4}\right) = -\,1,37$$

consequently $$\frac{1}{r_1} + \frac{1}{r_2} = \frac{2,37}{0,518} = 4,57$$

and $$-\frac{1}{r_3} + \frac{1}{r_4} = \frac{-1,37}{0,62} = -\,2,21$$

Now, $r_4 = \infty$, and $r_2 = -\,r_3$

so that $$\frac{1}{r_3} + \frac{1}{r_4} = \frac{1}{r_3} = -\,2,21$$

and $$\frac{1}{r_1} = 4,57 - 2,21 = 2,36$$

Therefore $$r_1 = \frac{1}{2,36} = 0,423$$

and $$r_3 = \frac{1}{2,21} = -\,0,452$$

while $$r_2 = 0,452, \text{ and } r_4 = \infty$$

These values are for unit focal length, and each must be multiplied by the focal length of the combination required in order to obtain the needed radii.

As we require a lens of 5-in. focus, the radii will be

$r_1 = 0{,}423 \times 5 = 2{,}115$ in.; $\quad r_3 = -0{,}452 \times 5 = -2{,}26$ in.;
$r_2 = 0{,}452 \times 5 = 2{,}26$ in.; $\quad r_4 = \infty$

If the lenses take the second form, an equi-convex cemented to a biconcave (Fig. 61), we have $r_1 = r_2 = -r_3$.

Let us select for the convex Mark 0,726, and for the concave 0,123 (Table, p. 80).

In this case $\quad \dfrac{1}{r_1} + \dfrac{1}{r_2} = \dfrac{36{,}5}{9{,}1 \times 0{,}54} = 7{,}42$

$$\therefore \frac{1}{r_1} \text{ or } \frac{1}{r_2} = 3{,}71 \qquad \text{and } r_1 \text{ or } r_2 = \frac{1}{3{,}71} = 0{,}269$$

$$\text{Also} \quad \frac{1}{r_3} + \frac{1}{r_4} = \frac{27{,}4}{9{,}1 \times 0{,}62} = 4{,}82$$

$$\therefore \frac{1}{r_4} = 4{,}82 - 3{,}71 = 1{,}11 \qquad \text{and } r_4 = \frac{1}{1{,}11} = 0{,}9$$

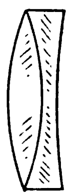


FIG. 61.

The radii are $r_1 + 0{,}269$, $r_2 + 0{,}269$, $r_3 - 0{,}269$, and $r_4 - 0{,}9$, which may be multiplied by five or any other number as before.

Although the new achromats furnish us with magnificent enses, it was found that the spherical aberrations were still imperfectly corrected; in fact, often less so than with the old glasses. Dr. Rudolph, by a happy inspiration, formed one of the combinations out of the Jena glass, and the other from the old type of glasses, with the best result. The Tessar lens, which stands unsurpassed by any photographic lens at the present day, is the result of such a combination.

SPECIAL PROPERTIES PERTAINING TO PHOTOGRAPHIC LENSES.

§ 33. **Focal Length.**—*Definition.*—The focal length of a lens *is the distance between its second equivalent point and the principal focus.*

The focal length may also be defined as the length of an image on the axis at the screen when its object at infinity subtends an angle of 45°. Thus let AB (Fig. 62) be an object at infinity, and *ab* its image. Since ABC, *abc* are similar triangles, the angle $u = u'$ and $\tan u = \tan u'$. But

$$\tan 45° = \frac{AB}{Bc} = 1, \text{ and } Bc = \frac{h}{\tan 45°} = h$$

therefore $bc = h'$, that is to say, the focal length of the lens is equal to the length of the image on the screen, and may be expressed by the formula

$$F = \frac{h'}{\tan u'} \quad . \quad . \quad . \quad . \quad . \quad . \quad [22]$$

Lastly, the focal length may be defined as *that distance measured along the optic axis through which the object must be moved to produce an increase or decrease of one magnification in the image* (Blakesley's definition).

The knowledge of the precise focal length of a microscopic or telescopic lens is quite immaterial to the user, but in photography it is often important. The stop rarely corresponds with the nodal point of emergence (second equivalent point), nor can

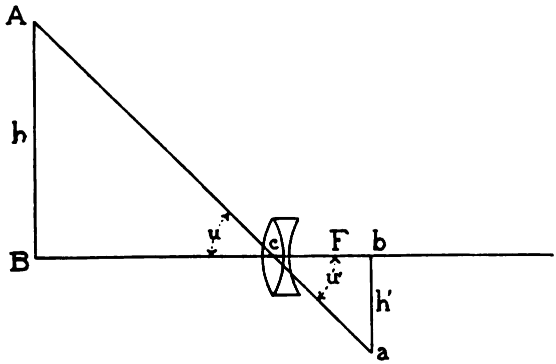


FIG. 62.—Diagram showing how the focal length is obtained.

this point be readily found unless the true focal distance is known, so that we must either adopt other means to find the points from which to take our measure, or else the focal length must be found independently. The true focal length may be found in several ways.

1. *By finding the nodal point.*—Determine the position of the principal point by rotating the lens placed horizontally on a sharp-pointed pivot, and shifting its position until no displacement of the image occurs when the lens is moved laterally through a small angle. Mark it accurately on the lens mount, and then measure the distance along the axis between it and the principal focus on the ground glass. The principal focus can be readily found by accurately focussing the sun, moon, bright star, or any other remote object.

The three following methods obviate the necessity of fixing the position of the nodal point:—

2. *Grubbs' method* (Fig. 63).—Mark off on a ground glass two fine ink dots, *a*, *b*, half an inch or an inch from the margin on each side (the distance apart does not much matter, but it is advisable not to have the points too near, as a very acute angle is difficult to measure accurately).

Place the camera on a sheet of paper on a horizontal table opposite the window, and hold it so that it can turn round a vertical axis without slipping. Focus a distant object, such as a chimney, so that its image falls on one of the ink marks, say *a*, and draw a line on the paper AB close against one side of the camera baseboard, using it as a straight-edge. Then turn the camera round, so that the same distant object falls exactly on the other pencil mark, *b*, and do the same with the other side of the baseboard, CD. This will give two lines inclined at a certain angle, AB, CD (Fig. 63).

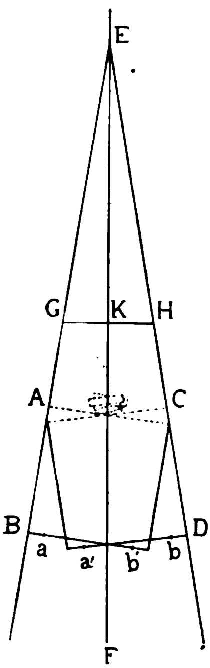


FIG. 63.—Grubb's method of finding the focal length.

Remove the camera from the drawing board and proceed as follows: Produce BA and DC till they meet at E. Bisect the angle AEC by FE. Draw GH at right angles to FE, so that GH equals the distance between the marks originally made on the ground glass. Bisect GH in K; then KE is the equivalent focal length. If GH is made equal to the base of the plate, then GEH equals the angle of view included by the lens.

3. *Conjugate method* (Fig. 64).—Focus the moon or other distant object, O. Mark the position of the screen on the baseboard, which is then at F_2. Rack back the screen to about double the focal length of the lens. Place a two-foot rule horizontally in front of the camera to form the new object O_1 at the same distance from the lens that the latter is from the screen. Make the necessary adjustments until I_1 and O_1 are equal in size when measured with compasses, and see that O_1 is

accurately focussed. The distance between the first and second position of the screen, *i.e.* between F_2 and I_1 will give the true focal length.

If we now measure this distance back from the screen to

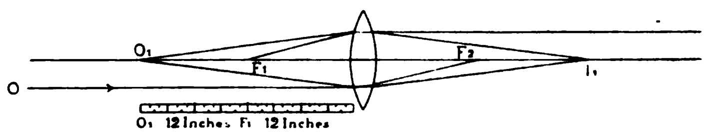


FIG. 64.—Conjugate method of finding the focal length.

the lens, we can at once determine the position of the nodal point and mark it on the mount, except in the rare cases in which it lies outside the latter.

4. *The angular method.*—This is a most admirable and highly accurate method, when once the angular interval between any two distant objects is known, and is equal in accuracy and infinitely more simple than Darwin's method, employed in the National Physical Laboratory. Take any two well-defined objects, such as a couple of telegraph posts which are situated at ∞. Infinity in photographic optics signifies any distance you please at which an object is placed when its image lies in the same plane as the principal focus; in other words, that distance which will give a crisp image of an object in the same plane as the image of the sun or moon. Measure the angle between the posts with a theodolite. Focus the two objects very carefully

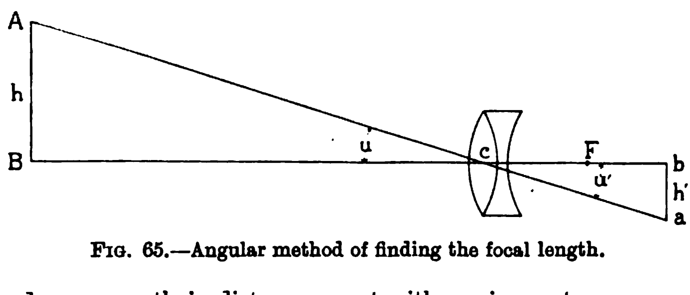


FIG. 65.—Angular method of finding the focal length.

and measure their distance apart with a micrometer gauge or fine compasses on the screen. This length divided by the tangent of the angle will give the true focal length of the lens, or

$$F = \frac{h'}{\tan u'} \quad . \quad . \quad . \quad . \quad . \quad . \quad [23]$$

Thus, let AB be the two objects (Fig. 65) which subtend an

angle of say 18° 26′.[1] Let $ab = h'$ be the image, and suppose it is found to measure 5,133 cm.

Then, from similar triangles, $\tan u = \tan u'$,

and since $\tan u' = \dfrac{ba}{bc}$, $bc = \dfrac{ab}{\tan u'}$,

or $F = \dfrac{h'}{\tan 18° 26'} = \dfrac{5{,}133}{0{,}3333}$ or $5{,}133 \times 3 = 154$ mm.

the true focal length of the lens.

Of course, once the angle is known, the focal length of any number of different lenses can be measured without further trouble. This measure is very useful for calculating the size of an image on the screen when the object is inaccessible. Thus, given a lens of 12 in. (300 mm.) focus, what would be the size of the image of the moon on the screen? The moon subtends an angle of about 32′, and the tangent of 32′ = 0,0093. Applying our formula $F = \dfrac{h'}{\tan u'}$, we find the size of the image

$$= F \tan u' = 300 \times 0{,}0093, \text{ or } 2{,}79 \text{ mm.}$$

i.e. about $\frac{1}{9}$ in.

Whenever, therefore, we see the moon in a photograph as large as a pea, we may be almost certain that it has been put in afterwards by the photographer, unless he has employed a high-power telephoto lens; for in the above example the focal length was 12 in., so that to get a picture of the sun or moon a quarter of an inch in diameter one would need a lens considerably over 2 ft. in focal length!

5. *Lionel Laurance's method.*—This method is superior to both Dallmeyer's[2] and Clay's, which take too much time to perform. The artifice consists in racking out the camera twice through a one-unit distance, by which the method is greatly simplified. Otherwise the principle is the same as Dallmeyer's. The method is as follows:—

[1] I suggested to Dallmeyer to place his two object test-marks so that they exactly subtended this angle. This simplifies the calculation immensely, since tan 18° 26′ = 0,3333, so that all you have to do is to multiply the height of the image by three, and the product is the true focal length.

[2] See "Traill Taylor Memorial Lecture," 1898. Dallmeyer's formula is

$$F = \frac{\sqrt{2l \times a \times c(c + a)}}{c - a}$$

Of course this scares the average amateur away, and he usually contents himself with measuring the back focus only, which won't help him at all.

1. Focus for ∞, mark the position of the screen S.
2. Move the screen back (from the lens) 1 unit $= n$ of the terms in which the F is expressed, to S_1.
3. Move an object (a fine glass scale illuminated by lamp behind is best) to and fro in front of the lens until the image is quite sharp on S_1 when seen through a magnifier. Mark position of O′.
4. Move the screen a second unit n' to S_2. n' is now two units from S.
5. Approach the object towards the lens until the image is again quite sharp on S, and locate the new position of O.
6. Measure the distance d between O and O′.

Then $$F = \frac{\sqrt{dnn'}}{n' - n} \quad . \quad . \quad . \quad . \quad . \quad . \quad [24]$$

But (and here lies the artifice) $n = 1$ and $n' = 2$. Therefore $n' - n = 1$, and the formula becomes

$$\underline{F = \sqrt{2d}} \quad . \quad . \quad . \quad . \quad . \quad . \quad [25]$$

This is the true focal length and independent of the equiva-

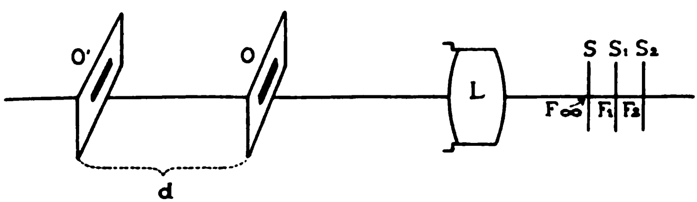


FIG. 66.

lent planes, which may be found by measuring forwards to the lens from F.

Example from my notebook: Let $n = 10$ cm. and n' 20 cm. and $d = 95{,}2$ cm. Taking 1 dm. as our unit, we have $n = 1$, $n' = 2$, $d = 9{,}52$ dm. Required the focal length of the lens.

$$F = \sqrt{2 \times 9{,}52} = 4{,}3638 \text{ dm.} = 43{,}638 \text{ cm.} \quad . \quad . \quad . \quad \textit{Ans.}$$

§ 34. **Methods of Finding the Focal Length of a Negative Lens.**—It is sometimes required to find the focal length of a negative lens, as in a telephoto combination.

Thin Negative Lenses.—1. If the lens is very thin (for example, a low-power spectacle lens) the focal length is easily

found by neutralizing with a positive lens of known focus, or by measuring the curves with a spherometer such as the Geneva lens measure, by which the power corresponding to the curve is read off on the dial.

2. If plano-concave, *i.e.* flat one side, the indicated reading = half the focal length of the lens.

3. If the lens is biconcave (equi-concave)

$$F = \frac{r}{2(\mu - 1)}$$

If $\mu = 1{,}5$, then $F = r$, *i.e.* the radius of curvature is equal to the focal length. The same applies to convex lenses.

Thick Negative Lenses.—If the negative lens is thick, it becomes much more difficult to find the focal length, as the

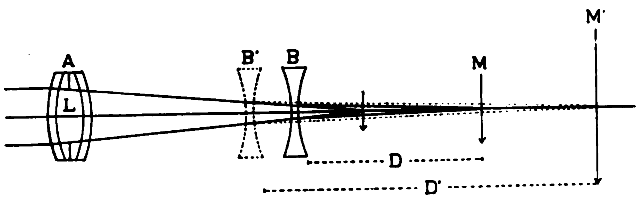


FIG. 67.

methods given in most of the text-books are perfectly useless in practice.

Lindsay Johnson's method.—This is merely Dallmeyer's method modified by the author so as to render it shorter and simpler. It is one of the very few ways known of measuring it exactly. The modification consists in making M′ − M = 1.

Let A be any positive lens, B the negative lens to be tested.

1. Measure the size of any image formed by A alone on the screen (indicated by the smallest arrow).

2. Place the negative lens to be tested within the positive focus at B, and move it until you get a sharp image at M exactly twice the size of the image above formed.

3. Measure the distance of this image from any point on the mount of B. Call this D.

4. Move B a little nearer towards A (indicated by the dotted outline) until the image M′ is exactly half as large again (*i.e.* three times the size of the positive image first formed).

5. Measure the distance of this final image from the mark on B. Call this distance D′.

Then the focal length of the negative lens or

$$F = \frac{D' - D}{M' - M} = \frac{D' - D}{3 - 2}$$

$$i.e.\ \underline{F = D' - D} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [\mathbf{26}]$$

In order to get the focal plane accurately, Clerc's twin diaphragm slot is most useful; this applies especially to the last two methods (see § 70, Fig. 137).

§ 35. **Illumination of the Field.**—It will be noticed that the illumination invariably decreases from the centre to the edge of the field. It is sometimes necessary to test the lens to find out whether the falling off of light exceeds the average for such a lens. The causes of diminution of light away from the axis of the lens are: (1) *The diaphragm.*—The further this is

FIG. 68.—Dr. Miethe's compensator.

away from the lens, or the greater the separation between the lenses, the more rapidly the circle of light becomes narrowed, assuming a pointed oval shape until under a certain measurable angle it is entirely cut off. (2) *The obliquity of the screen to the rays.*—The decrease of light is proportionable to the cosine of the angle ϕ which the rays make with the normal to the screen. (3) *The fact that the distance from the lens to the plate increases as the angle of view is extended.* This is proportional to $\cos^2 \phi$ by the law of inverse squares. Hence the two last causes together are proportional to $\cos^3 \phi$ or

$$I = \cos^3 \phi \quad . \quad . \quad . \quad . \quad . \quad . \quad [\mathbf{27}]$$

Sir W. Abney has designed a sort of Bunsen photometer at the focus of the lens between two sources of illumination, by which the falling off of the light can be accurately measured. As a remedy against this defect, Miethe has invented a compensator screen, which screws on to the lens, consisting of a plano-concave lens of clear glass cemented to a neutral tint plano-convex lens. The neutral tint glass being much thicker at the centre reduces the central illumination, and this helps to equalize the light on the plate. Stopping down the lens also tends to equalize the illumination.

§ 36. **Definition.**—This, quite independently of spherical aberration, depends on the size of the circles of confusion around each point of the image. The amount of blurring permissible (expressed by 2ϵ) depends not only on the nature of the photograph but on the size and distance at which it is intended to be viewed For pictorial images, such as landscapes and portraits, a picture the diameter (2ϵ) of whose circles of confusion do not exceed $\frac{1}{50}$ in. is said to possess good definition when viewed at ordinary reading distance, 12 in. to 15 in. Thus if an object be in motion while photographed, every point in it will appear as a line if the duration of exposure exceeds a certain fraction of time, but if the exposure be so short that the movement of the image does not exceed $\frac{1}{100}$ in. or ϵ (that is, of course, half the circle of confusion) the points will appear as points. Large prints, especially if made on rough paper, will allow of much more blurring than small prints, which latter, for the sake of perspective, require to be held nearer to the eye, and are usually printed on finer paper. For scientific work, such as micro-photographs, spectra of stars, drawings, etc., or for negatives which are intended to be enlarged several diameters, the blurring of a fine line or dot must never exceed $\frac{1}{250}$ in. or 0,1 mm. in diameter.[1] Indeed, most workers consider that the confusion circle should not exceed $\frac{1}{500}$ in. = 0,02, and some reckon it even as little as 0,01 mm. On the continent ϵ is always taken as = $\frac{1}{250}$ in. or 0,1 mm., and in England as = $\frac{1}{100}$ in., unless otherwise stated.

In the case of objects moving across the axis of the lens we can easily calculate the exposure which will just prevent blurring the image (see p. 194).

It is well to remember that no lens can be made absolutely achromatic for all rays, and therefore the longer the exposure the greater will be the blurring, since an increasing number of rays on the red side of the spectrum will act on the plate as the exposure becomes prolonged.

[1] Dr. Englisch has pointed out in his "Photographisches Compendium" that there is a limit to definition in the size of the particles of reduced silver which, if large, tend to blur the image. It is therefore most important in scientific work, especially in astro- and micro-photography, that the finest-grained emulsions (preferably collodion) should be employed. Slow plates give a finer deposit than more rapid ones. The size of the particles in very rapid plates varies from 0,003 to 0,004 mm. (or even 0,035 in some plates). Much sulphite of soda tends to dissolve the grains of AgBr, which reunite by fusion to form larger particles. Adjacent images smaller than the grains become indistinguishable (Englisch).

§ 37. **Rapidity.**—This depends on two factors:—(1) The ratio of the aperture (or, more correctly, the diameter of the cone of light) to the focal length of the lens, and (2) the loss of light by reflection and absorption. The latter factor is insignificant compared with the former, but it should be borne in mind, as it accounts for any discrepancy in the relative rapidity of two lenses, which should in theory be equal.[1] It may happen that the glass either possesses or acquires in course of time a light yellowish tinge, which, although it has no effect on the visual image, nevertheless seriously affects the rapidity for photographic purposes. It is said that lenses continually exposed to sunlight in shop windows are apt to become discoloured. Neglecting this, the rapidity of the lens depends entirely on the proportion between the focal length and the effective aperture. The greater the aperture the greater the quantity of light which enters the lens, and the longer the focal length the further is this light spread over in the image. Consequently the rapidity is greater as the effective aperture is larger or the focal length shorter. Now, the area of the lens or stop is proportional to the square of the diameter, and since intensity of illumination varies inversely as the square of the distance, the relative exposures required by any two lenses are as F^2/d^2, d being the diameter of the lens. When lenses are said to work at F/8, F/6,5, etc., the figures are obtained by dividing the focal length by the diameter of the stop and are called the intensity numbers or ratio apertures. They express the number of times the diameter of the stop is contained in the focal length. By squaring these numbers the relative light intensity or speed is obtained which gives the proportionate exposure required, but as the series F/4, F/5,6, F/8, F/11,3, F/16, F/22, F/32, F/45, F/64 are usually engraved on the lens mount, one has only to remember that each successive number requires double the exposure of the one preceding, and further calculation may be dispensed with. But without this aid the calculation is quite simple. Suppose a lens working at F/8 requires the $\frac{1}{20}$ second, what exposure must be given for a lens stopped down to F/32? Clearly the answer is

$$\left(\tfrac{32}{8}\right)^2 = 4^2 \times \tfrac{1}{20} \text{ sec., or 16 times as long, } i.e. \ \tfrac{4}{5} \text{ sec.}$$

[1] Speaking generally, a thickness of 4 cm. in a lens causes a loss of 31 per cent. of light (H. C. Vogel). Pebble (quartz) lenses let far more violet and ultra-violet rays through than glass lenses, and for that reason are much more rapid with the same ratio aperture than the latter (see p. 128).

Various systems have been devised for numbering stops so that the numbers give the relative exposures directly. The above series, although open to objection, is so widely adopted in this country, that it is doubtful if any change could be usefully effected (see Tables at the end of the book).

Since rapidity is inversely proportional to F, and the oblique rays are longer than the axial ones, the rapidity decreases towards the edges of the field. This is one of the causes of unequal illumination.

§ 38. **Definition of Certain Terms.**—1 *Achromatism* is that property of a lens which accurately brings to one focus any two given wave lengths of the spectrum. In a photographic lens the portions of the spectrum which must be united consists of the sodium (D) line in the yellow and either the G line or the hydrogen (H) line in the blue.

2. *Aplanatism* is the term used to describe the condition of a lens in which the axial definition is as good without a stop as with one; in other words, a lens free from chromatic and spherical aberration.

Abbe has extended the term aplanatic to mean a lens which is not only corrected for spherical aberration for any object-point situated on the axis beyond the principal focus, but it must fulfil the sine condition as well.

3. *Holostigmat.*—A term used by Messrs. Watson to describe their lenses, in which all points on the object form conjugate points on the image. A lens fulfilling this condition is necessarily aplanatic.

4. *Orthoscopic, or Rectilinear,* implies a lens free from distortion. Such a lens will render vertical and horizontal lines in the object parallel to the sides of the camera when the focussing screen is vertical. Nearly all symmetrically paired lenses possess this property, and it is this property which causes the rapid rectilinear lens to become so popular. Steinheil has named a type of lens which combines this quality with freedom from astigmatism *orthostigmat.*

5. *Collinear* is the term used by Voigtländer to describe a lens which gives a perfect image, that is, a distortionless, stigmatic image on a plane.

6. *Homocentric.*—A term used by Ross to describe a lens which has a complete zoneless spherical correction, in which the Petzval condition is maintained, so that all rays emanating

from any one point of the object are refracted by the lens into one point in the image.

7. *Stigmatic.*—Applied to a type of lens made by Dallmeyer, and also by Aldis, which brings vertical and horizontal lines to a common plane, *i.e.* one free from astigmatism. They are termed anastigmats by Zeiss.

8. *Isostigmar.*—A name applied by Beck to his recently invented lens, which unites rays proceeding from any point in the object plane to a corresponding point in the image plane. In other words, it means a lens which fulfils the sine condition for all points in the object plane.

§ 39. **Depth of Focus** is a convenient, but not strictly accurate term, used to describe the amount of racking movement (forwards or backwards) which can be given to the screen without the image becoming sensibly blurred, *i.e.* without any

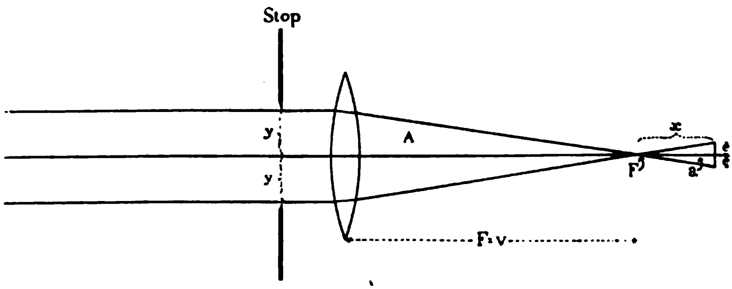


FIG. 69.—Diagram illustrating depth of focus.

blurring in the image exceeding $\frac{1}{100}$ in., or in the case of negatives to be enlarged or scientific work, the $\frac{1}{10}$ or $\frac{1}{100}$ mm. Then the breadth of a point of light which, of course, causes blurring on both sides, *i.e.* $\frac{1}{50}$ in. $= 2e$ (or $\frac{1}{100}$ in. $= e$).

Then if $F =$ principal focal length of lens, x amount of movement of screen in one direction without blurring, y half the breadth of the stop, then

$$\frac{x}{F} = \frac{e}{y}, \text{ and } x = \frac{eF}{y} \quad . \quad . \quad . \quad . \quad [28]$$

But as the screen can be moved equally for both ways the equation becomes

$$2x = \frac{2eF}{y} \quad . \quad . \quad . \quad . \quad . \quad . \quad [29]$$

As A and *a* are similar triangles, it is evident that as y

decreases x must increase; in other words, the depth of focus is inversely proportional to the diameter of the stop.

By substituting v for F the same formula will hold good for a near object.

§ 40. **Depth of Field** is precisely the same as depth of focus, only in the former case the depth is measured by the movement of the plate, the object being fixed, while in the latter case the depth is measured by the distance through which the object can be moved without the circle of diffusion exceeding $2e$.

Thus if a lens which is focussed for ∞ still gives a sharp image for an object at 6 yards, its depth of field is from ∞ to 6 yards, every object beyond 6 yards being in focus.

This distance (6 yards) is termed the *hyperfocal distance* of the lens, and any allowable confusion disc depends on the focal length of the lens and the stop used.

If the limit confusion of half of the disc (i.e. e) be taken as $\frac{1}{100}$ in., then the hyperfocal distance

$$H = \frac{Fd}{e} \quad . \quad . \quad . \quad . \quad . \quad . \quad [30]$$

d being the diameter of stop, or since $F/d = F/\text{No.}$ it equals

$$\frac{F^2}{F/\text{No.}} \times e \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [31]$$

or hyperfocal distance in feet

$$= \frac{100F^2}{12 \times F/\text{No.}} \quad . \quad . \quad . \quad . \quad . \quad . \quad [32]$$

This formula only applies when the plate is fixed in the principal focal plane of the lens. Mr. G. E. Brown has pointed out that in many fixed focus cameras the ∞ (infinity mark) on the scale is adjusted for a distance outside the true focal plane—in fact, at a distance intermediate between the two limiting planes at which the allowable confusion circles end, so that a slight circle of confusion already exists for objects at ∞. He recommends this plan, which is a good one, since one does not get an object in focus with the infinity mark on the screen, and we thus get more range. When this is the case the distances obtained by the above and following formulæ may be halved without much error.

Thus the hyperfocal distance of a 6-in. lens working at F/8 is

$$\frac{6 \times 75}{\frac{1}{100}} = 450 \text{ in., or } 37\tfrac{1}{2} \text{ ft.}$$

or, if you prefer the last formula

$$H = \frac{6 \times 6 \times 100}{12 \times 8} = 37\tfrac{1}{2} \text{ ft., as before}$$

Since 12×8 may be considered in this case as equal to 100 without any sensible error, the formula simplifies down to $H = F^2$ when e is taken as equal to $\frac{1}{100}$ in. We may therefore give the rule—

To find the hyperfocal distance of any lens working at F/8, "*take the square of the focal length in inches, and that number will give the distance in feet beyond which everything is in focus,*" or, expressed in a formula

$$H = F^2 \text{ (in feet)} \quad . \quad . \quad . \quad . \quad \textbf{[33]}$$

which in the above example = 36.

If $\frac{1}{250}$ in., or 0,1 mm., be taken as the limit of error, then multiply the product by $2\frac{1}{2}$ = 90 ft.

If the focal length be marked in centimetres and e be taken as $\frac{1}{100}$ cm., or 0,1 mm. (as is usual on the Continent), then, by the formula

$$\frac{Fd}{e} = \frac{15 \times 1{,}87}{\frac{1}{100}} = 2805 \text{ cm.} = 28 \text{ metres}$$

or 90 ft., as before.

This equation may also be simplified since

$$\frac{15 \times 1{,}87}{\frac{1}{100}} = \frac{15 \times 1{,}87 \times 100}{100} \text{ metres} = 15 \times 1{,}87$$

We may therefore give the rule—

To find the hyperfocal distance of any lens, *multiply the focal length in centimetres by its aperture, and the product is the hyperfocal distance in metres*, or, expressed in the formula

$$H = F \times d \text{ (in metres)} \quad . \quad . \quad . \quad \textbf{[34]}$$

Example.—A lens has a focal length of 22 cm. and its aperture is 2 cm. What is its hyperfocal distance?

$$22 \times 2 = 44\text{M}$$

which is quite correct when e is taken as $\frac{1}{250}$ in., or 0,1 mm.

Some photographers on the Continent prefer to make $e = \frac{1}{100}$ mm., or 0,01 mm. To suit them we only add a cypher to the product, so that, in the above example, H = 440M. To make it quite clear we give another example. A lens is 20 cm. in focal length. The stop used is $\frac{F}{16}$, and $e = 0{,}1$ mm. How far off is the nearest object in focus? By the ordinary formula

$$H = \frac{F \times d}{e} = \frac{20 \times \frac{20}{16}}{\frac{1}{100}} = 2500 \text{ cm.} = 25 \text{ metres}$$

By our short formula, $H = F \times d$, we get $20 \times 1{,}25 = 25$. *Ans.*

It is obvious, therefore, if we only remember these two formulæ we can dispense with tables altogether.

Lastly, the question sometimes arises: My lens has a focus of, say 16 cm.; what is the largest stop I can use without spoiling the picture, for a distance of 12 metres, taking 0,1 mm. as the limit of error? By the formula $H = F \times d$

$$d = \frac{H}{F} = \frac{12}{16} = 0{,}75 \text{ cm. or } 7{,}5 \text{ mm.}$$

so that we can use a stop of F/22, since 16/0,75 = 22 (approx.).

This is the principle which governs all so-called fixed-focus cameras, and enables us at once to fix the ∞ mark on the scale.

All the other distances nearer than ∞ are calculated by the usual formulæ, viz. $\frac{1}{F} = \frac{1}{v} + \frac{1}{u}$, or, if you prefer it,

$$xy = F^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [35]$$

where x is the distance of the object from the anterior focus of the lens, and y the distance of the image from the posterior focus.

Since $F^2 = xy$, or $y = \frac{F^2}{x}$, we find the distance the lens has to be extended from the original position when the focus is arranged for infinity (in this case, 25 metres), is equal to the square of the focal length of the lens divided by the distance of the object from the anterior focus of the lens.

In the above example, how much must the camera be extended beyond the ∞ plane to be in focus for an object at 2M?

$$\text{Here } y = \frac{F^2}{x} = \frac{16 \times 16}{200} = 1{,}28 \text{ cm.} \quad \textit{Ans.}$$

§ 41. **Covering Power.**—The covering power of a lens is measured by the diagonal of the largest plate over which it gives critical definition. Supposing a lens to be perfectly corrected, and to give equal illumination, this diagonal would be equal to the diameter of the circle of illumination given by the lens. But in practice it is much less than this, owing (1) to the rapid falling off of light as the edge of the field is approached, and (2) to the oblique aberrations which limit the definition. Thus a Petzval portrait lens with full aperture will only cover an area barely larger than the diameter of the lens itself, whereas an orthoscopic, stigmatic, or anastigmatic lens of recent manufacture, in which certain Jena glasses are used, will cover crisply an area whose base line equals one and a-half times the focal length, with a stop of F/16.

§ 42. **Circle of Illumination.**—It is often required to know whether the circle of view projected by any lens will cover a certain sized plate.

It must be remembered that the size of this circle of view is not altered by any stop, nor does the angle of view included in this circle vary with the magnification. Increase of magnification merely increases the size of the circle, but the view remains the same. It is, therefore, independent of the covering power.

A table giving the circle of illumination for various sizes of plates will be found in the appendix.

§ 43. **Angle of View.**—This is the angle subtended at the second equivalent point of the lens by the base of the plate used. According to the definition adopted at Kew, a lens is of

Narrow angle	when	the angle	of view	is below		35°
Medium	,,	,,	,,	from		35° to 60°
Wide	,,	,,	,,	,,		60° to 80°
Extra wide	,,	,,	,,	,,		80° to 135°

This latter angle is only covered by the Hypergon double anastigmat of Goerz, and the Pantogonal of Rodenstock, the diagonal of the plate being equal to five times the focal length. They have, however, an exceedingly limited sphere of usefulness.

Wide angle is not in itself a property of a lens, excepting that, owing to the back and front lenses being as thin and close

together as possible, it will allow of great obliquity of rays and so throw a larger circle on the screen.

A "narrow-angle" lens is one which cannot be used on a plate which would make it a "wide-angle," either because of oblique aberration which cannot be diminished by a stop, since rapidity is usually the speciality of the "narrow-angle" lens, or because its form does not allow a large circle illumination to be projected. It is, however, cheaper to make, and when used on a small plate is less likely to give rise to flare, since there are fewer rays to be reflected from the bellows than in the case of a wide-angle lens. A wide-angle lens, on the other hand, usually sacrifices rapidity in order that it may adequately cover a larger plate. Its chief use is in confined situations, where the operator cannot get far enough away to take in the picture with a narrow-angle lens. He therefore uses a wide-angle lens of shorter focus, which will still cover the plate, but being of shorter focus he can get more of the object into the picture. Of course a wide-angle lens can *always* be substituted for a narrow-angle one of the same focal length, and will then give identically the same picture both as regards size and other qualities, but owing to the small size of its illumination circle a narrow-angle lens cannot always replace a wide-angle one. Since the discovery of the properties of the Schott Jena glasses, most of the lenses now made are capable of transmitttng a wide-angle aplanatic cone, and, in addition are more rapid and give better marginal definition than the old narrow-angle lenses. They are, therefore, superior in every way.

Method of Determining the Angle of View. — In measuring the angle of view, either the *horizontal* diameter of the plate or the *diagonal* may be taken as the basis of measurement. The former comprises what is required to be known from an artistic point of view. The latter is necessary to enable one to judge whether a given lens will cover the corners of a plate or not. The first (horizontal) method is the most useful, and the solution can be arrived at immediately from a table of natural tangents.

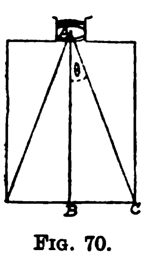


FIG. 70.

Let AB be the focal length of the lens, BC the semi-horizontal diameter of the plate, and θ the angle BAC = half the angle of view.

Then the angle of view, or 2θ, is clearly expressed by the formula

$$\tan\theta = \frac{\mathrm{BC}}{\mathrm{AB}} = x.$$

Opposite x in the tables we find θ in degrees and minutes.

Examples.—What is the angle of view of a 10-in. lens on a 10×12 plate?

$$\tan\theta = \tfrac{6}{10} = 0{,}6 \text{ and } \tan 0{,}6 \times 2 = 62°. \quad \textit{Ans.}$$

In the second method the diagonal of the plate is first measured, the half of which is substituted in the formula for BC.

Thus, in the above case

$$\tan\theta = \frac{7{,}8}{10} = 0{,}78, \text{ and } \tan 0{,}78 \times 2 = 76°.$$

For table of Angles of View, see Appendix.

§ 44. **Types of Photographic Lenses.**—1 *The Single Nonachromatic Lens*, such as an ordinary meniscus or plano-convex spectacle lens, is still used by certain amateurs, when stopped down, for the soft out-of-focus effects it gives, especially in portraiture of large heads. Moreover, it is more rapid than an achromatic lens of the same aperture, since crown glass lets more of the violet end of the spectrum through than does flint glass. To bring the chemical focus on a plane with the visual, the plate must be moved in towards the lens, after focussing, about $\frac{1}{50}$th of the focal length, according to the formula

$$\mathrm{F} - \mathrm{F}_v = \mathrm{F} \times 0{,}02 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [\mathbf{36}]$$

where F_v = focal length for the blue violet rays and F visual focal distance.

If the object be a near one it is necessary to multiply the square of the conjugate focal distance by 0,02 and divide the product by the focal length of the lens.

Example.—A 10-in. lens is focussed for an object 6 ft. away. How far must the plate be moved in to be in the right position for the image? Applying our formula $xy = \mathrm{F}^2$, we find y the distance of the lens from the image plane

$$= \frac{100}{72 - 10} + 10 = 1{,}61 + 10 = 11{,}61.$$

Therefore

$$\mathrm{F}_v = \frac{\mathrm{F}^2 \times 0{,}02}{\mathrm{F}} = \frac{(11{,}61)^2 \times 0{,}02}{10} = 0{,}27 \text{ in. (approx.)}$$

If the object were at ∞, the plate would have to be moved in 10 in. $\times$ 0,02, or 0,20 in.

The meniscus (periscopic) or the crossed lens,[1] should have the flatter surface towards the object if the latter is near, and the slot which holds the stop should be capable of adjustment both to and from the lens. For portraiture a stop of F/8 or F/11 may be employed, but I cannot recommend it for this purpose. It must be remembered that while for near objects the aberration is least when the flat side is towards the object, for distant objects better results are obtained by turning the lens round, since the rays then are approximately parallel.

I recently made a landscape lens consisting of a single piece of glass of an extremely curved meniscus, having a radius of curvature for the convex surface of only 28 mm. ($1\frac{1}{8}$ in.).

In this lens the diaphragm is placed approximately at the mean centre of curvature of the two surfaces, r_1 and r_2, so that rays from all parts of the field which pass through the diaphragm (if the diameter of the latter be not greater than $\frac{1}{16}$th of the focal length of the lens) will be normal to the surface, or so nearly normal that over an area equal to the focal length of the lens in diameter there will be sharp definition, without visible astigmatism or coma and very little curvature or distortion, since every bundle of rays which pass through the diaphragm must practically pass through the mean centre of curvature of the two surfaces. In other words, they form "chief" rays, and therefore will undergo an imperceptible amount of refraction. This form of lens, if the curvatures are properly proportioned to permit the mean normal of each bundle of rays to pass through the centre of curvature, will give a remarkably fine image, even with so large an aperture as F/16. The image then will be found to have no perceptible coma or astigmatism. The moment the aperture is increased beyond F/16 the coma suddenly appears and rapidly increases. The lens is therefore unsuitable for rapidly moving objects, except in a good light. When adjusted in the camera for chemical focus, and not used with a larger aperture than F/16, the image

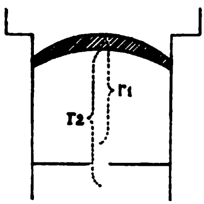


FIG. 71.—Lindsay Johnson's Deep Meniscus Single Lens.

[1] A biconvex lens which has its radii of curvature in the proportion of 1 : 6. It is sometimes called a lens of best form.

PLATE II.

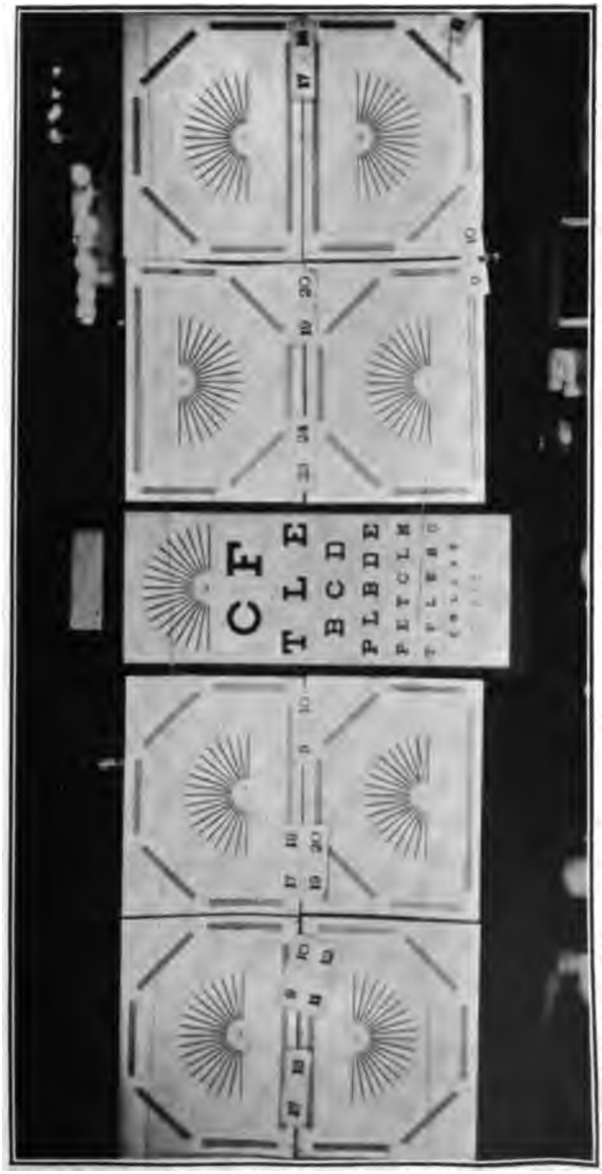


FIG. 72.—Photograph by the author, showing the definition of his deep meniscus single lens with the diaphragm placed at the centre of mean curvature. F/16, 8-in. focus.

To face p. 100.]

will bear favourable comparison with any R.R. lens in the market, made before the Jena epoch, and is unquestionably superior to any other form of single non-achromatic lens yet introduced. With orthochromatic plates and a yellow screen no alteration need be made for the chemical focus. I subsequently discovered that the celebrated Hypergon lens of Goerz is made on this principle, the two lenses forming a hollow sphere with the diaphragm midway between the two lenses.[1]

2. *The Landscape* (*Single Achromatic*) *Lens* may be made of two, three, or four separate lenses of different refractive indices and dispersion cemented together. It is nearly always in the form of a meniscus (Fig. 73). Since the modern achromatic doublets, used combined or singly, answer every purpose quite as

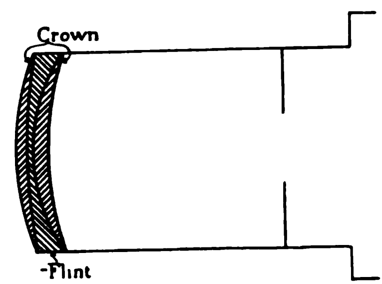


FIG. 73.—Single Achromatic Landscape Lens.

well as a landscape lens, they have superseded the latter almost entirely. The landscape lenses are larger in diameter compared with modern achromatic doublets, without any advantage in rapidity, since they are provided with a stop at some distance (sometimes exceeding the diameter of the lens) in front of its concave surface. Owing to its form, its maximum working aperture cannot exceed F/16 without some sacrifice of definition, and were it not for its cheapness, it would have been entirely rejected in favour of the modern anastigmat and other forms of rectilinear doublets.

[1] Commandant Puyo, of the French Army, has brought out an adjustable landscape single lens and also a portrait lens on the telephoto system, which he calls a "Téleanachromatique," which latter he recommends for portraiture. Each is an uncorrected single meniscus. The latter having two diaphrams, one in front and one behind the lens. They are said to give soft diffusion out-of-focus pictures, which may commend their use to some people, but I fail to see any advantage over my deep meniscus described above. They are very expensive. They are sold by the Grande Fabrique Française de Verres de Lunettes, 87, Rue de Turbigo, Paris.

It gives, however, a brilliant image, as it possesses only two reflecting surfaces, and the distortion at the margin may be ignored in ordinary landscape photography. It is also somewhat more rapid, as less light is reflected and absorbed.

In 1887 T. R. Dallmeyer, by displacing one of the crown elements of his landscape objective, and fixing it in a reversed position behind the other two, produced what is practically a non-distorting landscape lens. But on examination it will be found that there is an air space between the back and the flint.

3. *The Portrait Lens* (Fig. 74).—This is merely a name for a lens having a very large aperture compared with its focal length, so as to enable portraits to be taken in a studio in a short space of time.

It was invented in the year 1840, by Professor Petzval of Vienna, and maintains its reputation for excellence even at the

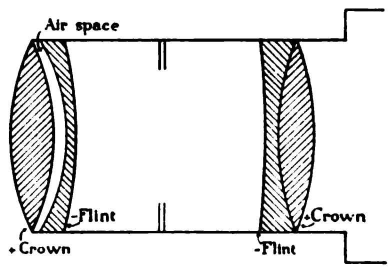


FIG. 74—Petzval's Portrait Lens.

present day. It consists of an anterior nearly plano-convex combination made up of an equi-convex crown cemented to a biconcave flint lens, the posterior surface of which is nearly flat. The posterior combination is composed of two lenses separated by an air space, the front element being a negative concave-convex flint separated by a narrow ring of brass from a positive equi-convex crown. The two combinations are separated by a space about equal to their diameter, the stop being placed between the two lenses and slightly nearer the front combination. The back combination not only shortens the focus, and so increases the rapidity of the lens, but owing to its excess of negative aberration, it neutralizes the positive aberration generated by the front combination, and this greatly extends the field of definition. J. H. Dallmeyer in 1866 entirely reconstructed this back combination, by substituting a

meniscus crown for the equi-convex element, and a shallow concave-convex positive meniscus for the negative meniscus in the former, and reversing the positions. We owe to the

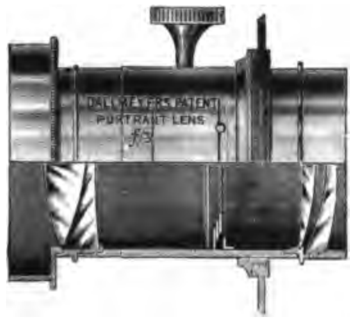


FIG. 75.—Dallmeyer's Improved Portrait Lens.

ingenuity of the elder Dallmeyer a considerable advance upon Petzval's work.

The former designed his portrait lens in such a manner that

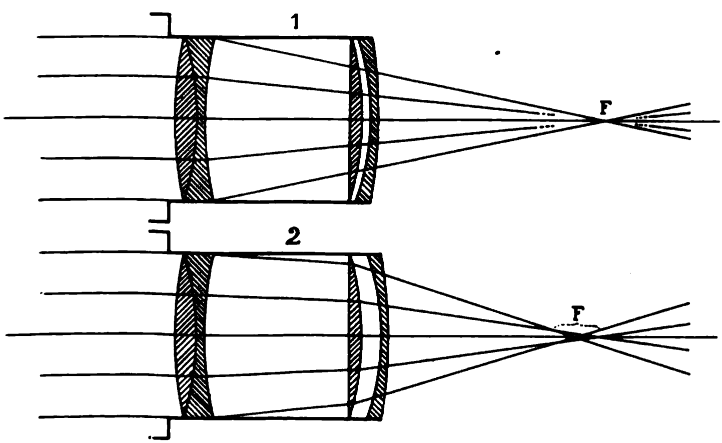


FIG. 76.—Dallmeyer's Improved Portrait Lens showing diffusion of focus produced by separation of the back element.

by slightly unscrewing and so separating the component elements of the back combination (Fig. 76) spherical aberration can be induced to almost any desired degree, thus lowering the

degree of definition but causing a general softness to spread over the image.

His portrait lenses are all fitted with indices graduated on the mount or back cell, whereby the extent of aberration produced can be ascertained.

The definition of the Petzval portrait lens, owing to its large size and full correction of chromatic and spherical aberrations, is superb over a small area (see Fig. 79), but there is considerable curvature of field and astigmatism, so that only an area slightly larger than the diameter of the lens can be sharply covered. It is not entirely free from distortion, and may give rise to flare with a small stop. It is necessarily very rapid, working at F/4. One form even works at F/2,5, and in consequence its depth of focus is almost nil. The illumination falls off rapidly towards the edge of the field. It is mainly suitable for

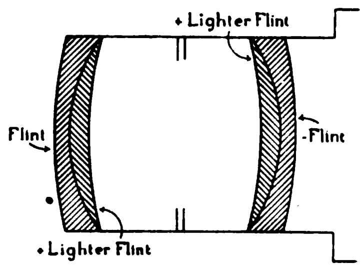


FIG. 77.—Diagram of an R.R. Lens.

portraiture, but forms an admirable lens for the optical lantern and telephotography, and also for astro-photographic purposes, in which a small angle is required to be covered.

In recent years Dallmeyer, Taylor, Aldis, Ross, Zeiss, Goerz, Beck, Steinheil, Voigtländer, and Watson have all produced superb portrait lenses by the employment of certain of the Jena glasses which work at F/2,5 to F/4,5, and are entirely free from astigmatism, distortion, and flare. For very high rapidities (F/4 and over) the Petzval type is still largely adhered to.

4. *The Rapid Rectilinear.*—Perhaps no lens has been so universally popular as the rapid rectilinear. Although its day is past, it still holds its place for the cheaper cameras. It is formed of two identical combinations having their concave surfaces facing one another with a stop between them.

The two together neutralize the distortion produced by either lens singly. Each combination consists of a negative meniscus flint glass lens cemented to a positive meniscus crown or a much lighter flint than the exterior one. This form of lens is, like the next group, universal in its application, being adapted for groups, landscapes, architecture, and copying. Either combination may be used separately, when it will approximately double the focal length, and increase the exposure of the combined lens fourfold. It should cover at least an angle of 45° sharply with full aperture, F/8, and a plate whose longer side is equal to its focal length (in about 54°) with a small stop. Like all lenses made with the ordinary flint and crown glass, curvature of field, astigmatism, and coma are invariably present. The central spherical correction is of the highest order, but in point of rapidity and marginal definition this type must be classed as of medium quality. The lenses are about a third the price of those in the next group.

Some of the lenses of the rectilinear type are made to work at F/6 and go under the name of "Euryscopes," but the extra rapidity is obtained at the expense of definition, and they are inferior to the ordinary R.R. lenses in defining power.

5. *The Astigmat or Anastigmat.*—All the lenses we have been discussing are made of glass only available before the Abbe-Schott epoch. Each combination, as a rule, consisted of a positive crown, united to a negative flint. Now, in order to get a perfectly flat image it is necessary that the convergent lens of shorter focal length should have a higher refractive index than the concave lens. In lenses achromatized by the old style of glasses it is impossible to get a perfectly flat field free from astigmatism, since the refractive index of the crown was of necessity less than that of the flint. Achromatism requires the stronger lens to be of crown and the weaker of flint, while flatness of field consistent with freedom from astigmatism requires that the stronger lens be of flint and the weaker of crown. The two conditions are attained by combining glasses such that high refractivity is obtained with low dispersion and low refractivity with high dispersion.

The invention of such glasses by Schott & Co. at Jena caused a new epoch in photographic lens making, with the result that a large variety of lenses conforming to Von Seidel's five conditions have been produced. Nearly all work with much greater intensity, *i.e.* with larger apertures, than the

corresponding lenses made with the older glasses.[1] Many cover with F/16 a plate whose longest diameter equals one and a-half times the focal length of the lens. They more or less perfectly fulfil Abbe's sine condition, and are remarkably free from astigmatism, curvature, chromatic and spherical aberrations, and give no distortion whatever. Consequently they have, to a very large extent, replaced both landscape and rapid rectilinear types of lenses; in fact, were it not for their cheapness, the latter types would cease to be made.

All rapid rectilinear lenses and all the symmetrical doublets and most achromats, have the front and back combinations separately corrected for aberrations, so that they can be used as single lenses by removing the front combination. In this case, if the doublets are identical, the exposure must be four times

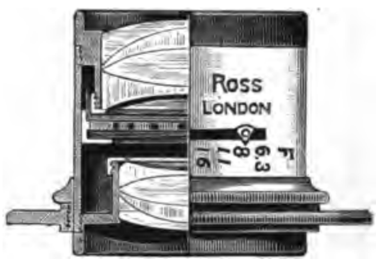


FIG. 78.—The Protar Lens. A typical anastigmat built up of eight lenses.

that of the complete lens, since the aperture remains the same, but the focal length is doubled. Some lenses, such as Zeiss' Doppelprotar, Beck's Orthostigmat, Dallmeyer's Stigmatic, and Watson's Holostigmat, have a different focus for each combination, whereby three distinct foci can be obtained, one for each combination, and a shorter one for the entire lens. Theoretically, the front element, if used alone, should be unscrewed and attached to the back of the mount, but practically there is no difference which side is turned to the light. Since the focus is greatly lengthened when the single element is used, the circle projected is so much larger than the plate, and moreover, the stop is so near the lens that the inevitable distortion of straight lines is rarely perceptible, *even at the extreme edge of the screen*,

[1] Exception must be made to the special Petzval portrait lenses of the older type, which work with an intensity of F/4, F/3, and over.

PLATE III.

[*Copyright.*

Gannet alighting on her nest. Photographed by H. Armytage Sanders with his Birdland Camera; time $\frac{1}{300}$ sec., using the back combination of a Goerz lens.

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while the illumination is of course much more even. The single combination may therefore be used for architecture if the horizon does not much exceed half the focal length of the lens, *i.e.* 30° to 35°.

The diagrams drawn below illustrate the definition given by the four main types of lenses. The horizontal line *b* is the plane of perfect definition. The width between the two parallel lines *a* and *b* shows the limit of permissible error, or "*e*." Any deviation not exceeding half the distance between the two lines may be considered as crisp definition. It will thus be seen that, counting the error on both sides of *b*, the landscape covers about

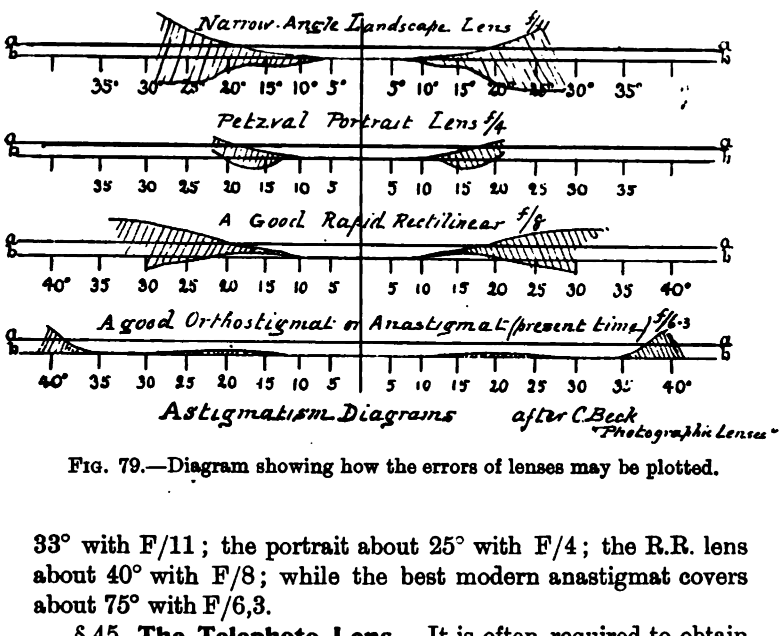


FIG. 79.—Diagram showing how the errors of lenses may be plotted.

33° with F/11; the portrait about 25° with F/4; the R.R. lens about 40° with F/8; while the best modern anastigmat covers about 75° with F/6,3.

§ 45. **The Telephoto Lens.**—It is often required to obtain a larger magnification of a distant object in a landscape than is possible with ordinary cameras, or to take a portrait with a camera which will not allow of a sufficiently large image without undue proximity to the sitter, with the consequent exaggerated perspective of the hands and feet. To meet these difficulties the telephoto lens was brought out. This is nothing more than an application of corrected lenses adapted to photography on the principle of the Galilean telescope, and may

therefore be said to date from the time of Galileo and Porta. Photographic lenses fitted with a movable negative lens were first used by Porro for photographing an eclipse so far back as 1857, and Steinheil constructed one for the Brussels Observatory in the year 1889, but it was not until two years later that Dallmeyer in London, Dubosq in Paris, and Dr. Miethe in Berlin, simultaneously, but quite independently, introduced a really practical telephoto lens capable of being adapted to any camera. The chief improvements which have been made since that time have been in the better correction of the lenses, while the principle of all of them remains unaltered. This consists of the addition of a divergent (negative) lens placed between the usual photographic lens and its posterior focus, whereby the convergence is greatly reduced, so that not only is the focus

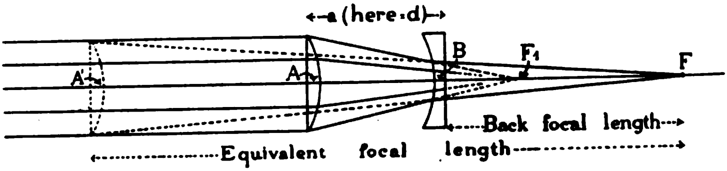


FIG. 80.—Diagram showing how the equivalent planes are shifted and consequent focal length increased by the addition of a negative lens behind the positive element.

shifted back, but the lens is virtually shifted forward to a plane beyond the real lens.

We would call attention to the fact that a very deep meniscus lens can be constructed so that its equivalent planes are entirely outside the lens, and at a considerable distance beyond the convex surface. It thus acts as a telephoto lens when the convex surface is turned towards the object. Busch has brought out a fixed focus telephoto lens which gives about two magnifications constructed on this plan. It consists of two unsymmetrical combinations separated by a considerable interval.

This is shown in Fig. 80. Here A is the positive lens, B the negative lens, $a =$ the distance between the optical centre of the two lenses; and $d =$ the distance of separation *in excess of the difference between the focal length of the two lenses.* In this case A and B are supposed to have the same focal length, so that the difference between their focal lengths $f_1 - f_2 = 0$, and

therefore $a = d$. B lies between A and its principal focus F_1, so that the convergent rays, instead of coming to a focus at F_1, are rendered divergent by the negative lens B, and the focus is now extended to F. The distance BF is called the back focal length (F_2). If these extended rays are produced backwards they will appear to proceed from A′ instead of A. The distance A′F will therefore be the true focal length of the compound

FIG. 81.—Construction of a Telephoto Lens (Dallmeyer).

lens when the two lenses are separated by the interval d. In actual practice the negative lens of a telephoto combination has invariably a shorter focal length than the positive one, and it is placed at a relative distance away according to the

FIG. 82.—Dallmeyer's "Adon" Telephoto Lens.

magnification required, the distance being varied at will, between certain fixed limits.

Fig. 81 shows a stigmatic positive lens affixed to a telephoto attachment (negative lens). The latter screws on to the camera, the ordinary lens being attached in front of it.

The effect produced by a telephoto combination depends entirely on the position of the negative lens with respect to the

positive element. There are six possible positions to consider. Let us, for the sake of argument, assume that the positive lens A = 6 in. focus, and the negative lens B = 3 in. focus.

1. *The two lenses are in contact.*—In this case the combination $F_2 - F_2$, or $\frac{1}{6}-\frac{1}{3} = -\frac{1}{6}$, resulting in an excess of negative power, so that no real image can be formed (Fig. 83 (1)). If both lenses were of equal power, the two together would act like a piece of plain glass and the rays would pass out unaltered, as at *f, f, f*.

2. On slight separation the focal length of the combination continues to be negative (Fig. 83 (2)); until

3. The separation $a =$ the difference of their focal lengths,

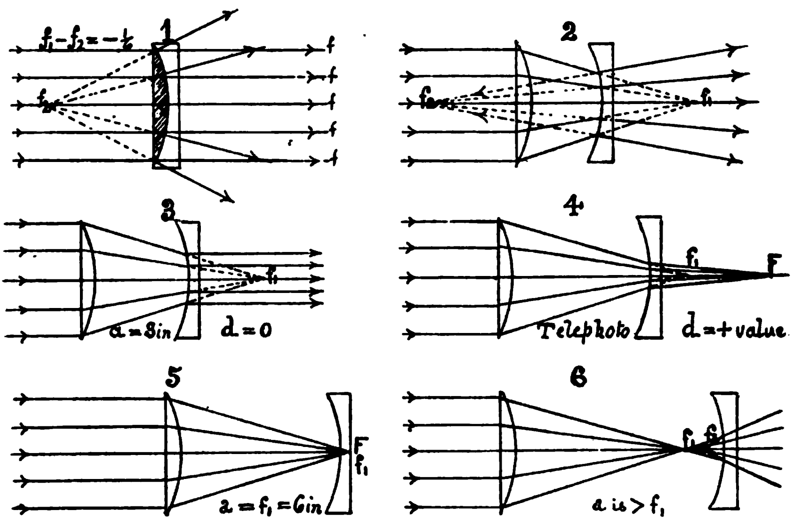


FIG. 83.—Diagrams illustrating the six possible positions of the positive and negative lens combinations.

i.e. $a = 3$ in. In this case $d = 0$ and the combination has its focus at ∞. *This is the condition which obtains in a telescope or opera-glass adjusted for* ∞ (Fig. 83 (3)). It is known as the "telescopic condition."

4. The slightest further increase of separation causes d to assume a positive value, so that a real inverted image is produced which can be focussed on a screen (Fig. 83 (4)). *This is the condition which exists in a telephoto lens.*

5. As the separation increases the focal length of the combined lenses decreases, until the negative lies in the focal plane

of the positive lens. In this case $a = f_1$ (here = 6 in.), so that the focal length of the combination is at its minimum, and the negative lens has no effect whatever (Fig. 83 (5)). It is therefore obvious that *for a telephoto lens the condition illustrated in Fig.* 83 (4) *is the only one of practical value*, and the range of the lens extends to the position in which $a = f_1$ (Fig. 83 (5)).

6. Any further separation causes the negative lens to produce a virtual image of the focal point formed by the positive lens at f_1, which image always lies between f_1 and the negative lens (Fig. 83 (6)). It would be well if every optician would make $d = 0$ the starting-point, and mark it on the mount of the combination, for if we take the former case, in which a 6-in. lens is combined with a 3-in. lens, it is extremely difficult to separate the two lenses by 3 in., since the position of the equivalent planes must first be found; but it is very easy, knowing the focal lengths of each element, to separate them *until rays which enter the first lens emerge parallel from the second one*, then the distance between the equivalent planes can be found at once, since it is equal to the difference between their foci.

The focal length of the entire system, F, is always equal to the focal length of the positive and negative lenses multiplied together and divided by *d*. In the above case, as $d = 0$

$$\mathrm{F} = \frac{f_1 f_2}{d} = \infty \quad . \quad . \quad . \quad . \quad . \quad [37]$$

If we increase the separation by half an inch

$$\mathrm{F} = \frac{f_1 f_2}{\frac{1}{2}} = 6 \times 3 \times 2 = 36 \text{ in.}$$

If we make $d = 1$ in., then

$$\mathrm{F} = \frac{f_1 f_2}{1} = 18 \text{ in.}$$

Dallmeyer adopts the plan of engraving the focal lengths on the mount opposite each fraction of an inch of separation, by which the photographer can know at once the focal length for any degree of separation.

1. *Magnification.*—We may consider the telephoto lens as consisting of two separate parts, a positive lens which forms an image, f_1, in the usual way, and a negative lens which intercepts the image, and enlarges it in inverse proportion to the length of

d (Fig. 83). The screen may be placed anywhere we choose behind the negative lens, and the linear magnification M (*i.e.* the number of times the image of the combination is greater than that of the single positive lens) is obtained by the formula

$$M = \frac{E}{f_2} + 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [38]$$

Hence, to obtain the magnification, divide the camera extension, E (i.e. *the back focus, or the distance from the back of the negative lens to screen) by the focal length of the negative lens, and add one.*

Since the anterior and posterior focal lengths are exactly the same in all lenses or lens systems in air, it is clear it will make no difference to the magnification of the picture whether a telephoto lens has the positive or negative element in front. The images will be identical, but the circle of illumination will be greatly restricted in the latter case. This is the defect of Dallmeyer's Adon lens, which gives a miserably small picture when placed in front of an ordinary positive lens, but when used *alone* with the positive element in front, it gives a large and well-defined image (Fig. 82).

2. *Extension.*—By transposing the above formula we find

$$E = f_2(M - 1) \quad . \quad . \quad . \quad . \quad . \quad . \quad [39]$$

i.e. the extension necessary is equal to the focal length of the negative lens multiplied by the magnification, less one.

Examples.—Taking, as before, $f_1 = 6$ in., $f_2 = 3$ in., what would the magnification be for an extension of 12 in.?

Here $M = \frac{E}{f_2} + 1 = \frac{12}{3} + 1 = 5$ times, *i.e.* the image is five times as large as is produced by the single lens alone.

A magnification of three and a half times is required; to what length must the camera be pulled out?

The formula is

$$E = f_2(M - 1) \quad . \quad . \quad . \quad . \quad . \quad . \quad [40]$$

$= 3 \times (3\frac{1}{2} - 1) = 7\frac{1}{2}$ in.

3. *Focal Length.*—In order to find the focal length of the combination for any extension of camera the formula is

$$F = Mf_1, \text{ or } F = \frac{Ef_1}{f_2} + f_1 \quad . \quad . \quad . \quad . \quad [41]$$

or, *to obtain the focal length of the system multiply the focal length*

of the positive lens by the magnification. In the above example $M = 3\frac{1}{2}$, and, since $f_1 = 6$ in., F must be 21 in. By the other formula

$$F = \frac{7\frac{1}{2} \times 6}{3} + 6 = 21 \text{ in. as before.}$$

Thus it will be seen that with an extension of $7\frac{1}{2}$ in. a telephoto lens gives the same sized image as an ordinary camera extended to 21 in.

4. *Exposure*—It is necessary to calculate the relative exposure, *i.e.* compared with a positive lens of the same aperture. The formula is

$$T = M^2 t \quad . \quad . \quad . \quad . \quad . \quad . \quad [\mathbf{42}]$$

or, *the exposure for the telephoto lens is equal to that of the positiv lens, multiplied by the square of the magnification.*

Thus, if an ordinary lens working at F/8 requires $\frac{1}{10}$ sec., what exposure would a telephoto lens require which gives a magnification of six times with a ratio aperture of F/4 ?

$$T = \frac{36 \times \frac{1}{10}}{4} = \frac{9}{10} \text{ sec., or nine times as long.}$$

The intensity of the telephoto lens is equal to the intensity, i, of the positive lens divided by the magnification, or

$$I = \frac{i}{M} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [\mathbf{43}]$$

Thus if the lens has an intensity of F/4, and the magnification of the combination = 8 times, then its intensity $I = \frac{F}{4 \times 8} = \frac{F}{32}$ but the exposure will need to be as $4^2 : 32^2$, *i.e.* 64 times that of the positive lens.

5. *Aperture.*—The effect of this is worth noticing. Lord Raleigh has shown that, theoretically, an aperture less than F/72 should not be used, that is to say, with a combination magnifying 18 times the aperture ought not to be less than F/4 or F/6, with 12 magnifications, or F/8 with 9 magnifications, but this does not hold good for telephoto lenses, since excellent photographs have been taken with F/240 quite free from diffraction effects. The explanation is that owing to the great focal length, the aperture (notwithstanding the very low intensity) is relatively great as regards the size of a wave length, in other words, the number of

waves which pass through undisturbed, is very great compared with those waves which strike the margin of the lens.

6. *Size of Image.*—The size of the image formed by the positive lens alone is always $\frac{1}{n}$th the size of the object. This image is magnified M times by the negative lens, so that, if $\frac{1}{\mathrm{N}}$ represents the entire magnification of the object by the telephoto lens, then

$$\frac{1}{\mathrm{N}} = \frac{1}{n} \times \mathrm{M} \quad . \quad . \quad . \quad . \quad . \quad . \quad [44]$$

If unit magnification, *i.e.* life-size, is required, then $\mathrm{N} = 1$ and $\mathrm{M} = n$.

If the image is to be half-size

$$\frac{1}{\mathrm{N}} = \frac{1}{2} \text{ and } \mathrm{M} = \frac{n}{2}$$

Example.—The focal length of the positive lens is 8 in., that of the negative lens 3 in., and the object 60 in. away. It is required to produce an image half the natural size. What must the camera extension be? Now we know, from our fundamental formulæ, that the object bears the same proportion to the image that the focal length of the lens does to the distance of the object from the front focus of the lens, or

$$\frac{\mathrm{O}}{\mathrm{I}} = \frac{\mathrm{F}}{x} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [45]$$

or

$$\frac{\mathrm{O}}{\mathrm{I}} = \frac{8}{60 - 8} = \frac{1}{6\frac{1}{2}}$$

The image produced by the positive lens alone is therefore $\frac{1}{6\frac{1}{2}}$ the size of the object, but the final image is required to be half life-size. This image must therefore be magnified by the negative combination three and a quarter times. In order to find the extension of camera necessary we can use the formula given above, viz. $\mathrm{E} = f_2(\mathrm{M} - 1)$, *i.e.* $= 3(3\frac{1}{4} - 1)$, or $6\frac{3}{4}$. We must therefore extend the camera $6\frac{3}{4}$ in.

7. *Focal Length of the System for Parallel Rays*, i.e. *for an object at* ∞.—This is important for determining the intensity of the lens.

Let the distance between the negative lens and the focus of the telephoto lens for parallel rays = X. Let $\frac{1}{\mathrm{N}}$ = entire

magnification produced by the telephoto combination. Then the distance of the focus from the screen $= \frac{F}{N}$. Let E = camera extension and m the multiple $= f_1/f_2$ or number of times the focal length of the positive lens is greater than that of the negative lens.

Then $$X_2 = E - \frac{F}{N} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [46]$$

and $$F = mX + f_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [47]$$

hence $$F = m\left(E - \frac{F}{N}\right) + f_1$$

or $$F\left(\frac{m}{N} + 1\right) = mE + f_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [48]$$

and $$F = \frac{mE + f_1}{\frac{m}{N} + 1}$$

which gives the focal length of the telephoto system for ∞.

Taking the last example

$$m = \tfrac{8}{3} = 2\tfrac{2}{3}, f_1 = 8, E = 6\tfrac{3}{4}, \text{ and } \frac{1}{N} = \tfrac{1}{2}$$

we get by [48] $F\left(\frac{2\frac{2}{3}}{2} + 1\right) = 2\tfrac{2}{3} \times 6\tfrac{3}{4} + 8$

i.e. $2\tfrac{1}{3}F = 26$, or $F = 11\tfrac{1}{7}$, the focal length required.

N.B.—This true focal length must not be confused with the conjugate focal length described under Heading 3.

8. *Intensity.*—If we know the focal length we can obtain the intensity of the lens by dividing it by the diameter of the stop.

The above example shows the advantage of a telephoto lens since an extension of only $6\tfrac{3}{4}$ in. and a focal length of $11\tfrac{1}{7}$ in. are required to get a half-sized copy of an object 60 in. away; whereas with an ordinary lens a focal length of $\tfrac{60}{3}$, or 20 in., and the extension of $\frac{n+1}{n}$ F = 30 in. is required.

9. *Covering Power.—To find the diameter of a circle thrown on the screen.*

This can be done by the following formula:

$$D = \frac{d}{f_2} \times \frac{af_1 + bf_2}{f_1 - f} \quad . \quad . \quad . \quad . \quad [49]$$

Thus, let the focal length of the + lens, $f_1 = 6$ in.

Let the focal length of the negative lens, $f_2 = 3$ in. Let the aperture of the positive lens, a, and negative lens, b, each $= 1$ in., and the distance, d, of the negative lens from the plate $= 12$ in. Then the diameter of the circle on the screen will be $\frac{12}{3} \times \frac{6+3}{3} = 12$ in.

§ 46. **Certain Special Forms of Lenses.**—1. *Fixed Telephoto Lens.*—This consists of the usual positive and negative elements separated by an interval. As the lenses are fixed in the mount no adjustment is possible. It is very useful where considerable magnification is required on a short or fixed focus camera. The Busch Optical Company make a series of these lenses under the name of "Bistelar." Thus the 7-in. focus lens requires a camera extension of $4\frac{1}{8}$ in. The 10-in. focus lens requires $5\frac{1}{2}$ in. extension, and the 14-in. lens only $8\frac{1}{4}$ in. extension, in other words, they give nearly double the size of image that the extension of camera will allow of with an ordinary objective. They are useful lenses, but the definition is certainly inferior to their "Omnar" anastigmats.

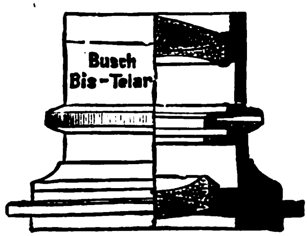


FIG. 84.—The Busch Bistelar Lens.

2. *Lepersonne's Fixed Anachromatic Telephoto Lens.*—Those who prefer the soft effects produced by spectacle lenses (*i.e.* lenses uncorrected for colour) may adopt Lepersonne's modification of Puyo's anachromatic lenses. This is effected by mounting in a tube a plano-concave and a plano-convex lens made from the same glass and of equal radii of curvature, the positive power being obtained by the separation. In order to get the best results the two plane surfaces are put facing each other, the convex surface being directed outwards towards the object. In this case the extension of the camera = back focus, or the distance of the negative element from the plate. Such a combination forms a fixed telephoto lens similar in action to the Bistelar, except that the chromatic aberration is entirely uncorrected, with the result that where used with a large aperture there is a general diffusion of focus. The lens is so exceedingly simple of construction that any amateur can make one for himself.

Let us suppose we require a lens to use with a half-plate camera which has an extension of 16 in. By making a telephoto combination we have abundance of choice. Take, for example, a positive and a negative plano-spherical, each 6 in. in focal length. If we fit the positive into a tube which slides inside the tube holding the negative lens, we can get any focal length we choose. All we have to take care is that the back focal length (F_B) does not exceed the camera extension. Since $F_1 = F_2$ the separation between the lenses ($= a$) is the same as d (the increase of separation greater than the difference between the focal lengths of the two lenses). (See Fig. 80.)

Now $$F = \frac{F_1 F_2}{d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [50]$$

or the equivalent focal length of our telephoto system is equal to the product of the two focal lengths divided by the interval of separation. Thus supposing we separate the components 1 in., the focal length will be $\frac{6 \times 6}{1} = 36$ in.

Also $$F_B = \frac{F_2(F_1 - a)}{d} \quad . \quad . \quad . \quad . \quad . \quad . \quad [51]$$

or *the back focus is equal to the negative focal length multiplied by the (positive focal length less the interval) and divided by the interval of separation between the two components.*

Thus in the former case $F_B = \frac{6(6-1)}{1} = 30$

If we separate the lenses

1 in.	$F = 36$	$F_B = 30$
2 in.	$= 18$	$= 12$
$2\frac{1}{2}$ in.	$= 14{,}4$	$= 8{,}4$
3 in.	$= 12$	$= 6$
$3\frac{1}{2}$ in.	$= 10{,}3$	$= 4{,}3$
4 in.	$= 9$	$= 3$
6 in.	$= 6$	$= 0$

Hence the total focal length is equal to the F_B + the focal length of the positive lens, and the magnification

$$M = \frac{F_B}{F_2} + 1 \quad . \quad . \quad . \quad . \quad . \quad [52]$$

Thus, by separating the two elements 2 in. we get a

magnification of $\frac{12}{6}+1$, or three times greater than that obtained by the positive lens alone, which is quite within the reach of our camera extension. Such a lens can be made to work at about F/8 or F/10.

Moreover, since both the positive and negative lens have the same focal length and index (being made from the same glass), all difficulty in fulfilling the Petzval condition is done away with, since $\frac{\phi_2}{\phi_1}=\frac{\nu_1}{\nu_2}=\frac{\mu_1}{\mu_2}$ by necessity. If the proper curves and the best distance, d, be chosen a really good and nearly achromatic lens can be made. The Beck-Steinheil Unofocal is a modification of this type.

3. *The No-Curvature Lens.*—This is a meniscus lens in

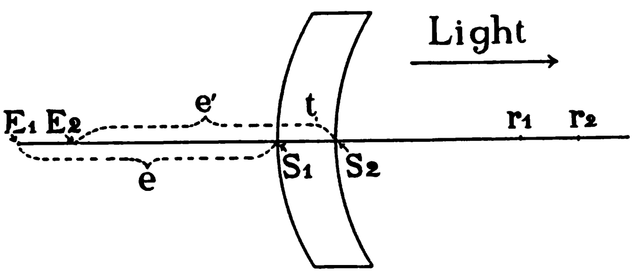


FIG. 85.

which both surfaces have the same radius and on the same side. It is therefore identical with a piece of bent glass. (See p. 68.)

Let r_1, r_2 be the centres of curvature of the two surfaces S_1 and S_2 respectively; E_1 and E_2 the first and second equivalent points; e the distance E_1S_1; e' the distance E_2S_2; t the thickness of the lens.

Then N (a constant) $= -d(\mu-1)$

Also $$r_1 = r_2 = r$$

$$e = -\frac{r_1}{\mu-1} \quad \text{[53]}$$

$$e' = \frac{r_2}{\mu-1} \quad \text{[54]}$$

and $$F_1 = F_2 = \frac{\mu r^2}{t(\mu-1)^2} \quad \text{[55]}$$

Example.—Suppose $\mu = 1{,}5$, $t = 4$, $r = 10$. Then $e = -20$, $e' = 20$, and $F = 150$. If $t = 2$, $F = 300$. If t were made equal

to 10, F would be 60. If $t = 0$, F would become infinite. From this it is evident that the power of the lens is direcily proportionate to its thickness.

Such a lens shows remarkably little astigmatism. Nearly all astigmats and anastigmats, consisting of 2, 3, or 4 cemented combinations, are made approximately on this plan, *i.e.* the front and back surfaces of the cemented combination have hardly any difference of curvature. It will thus be seen that the no-curvature lens is practically the same as the Unofocal combination, in which the air space between the two elements is filled up by glass so as to form one solid piece. It therefore, like the Unofocal, fulfils the Petzval condition.

4. *The Concentric Lens.*—This is a lens in which both

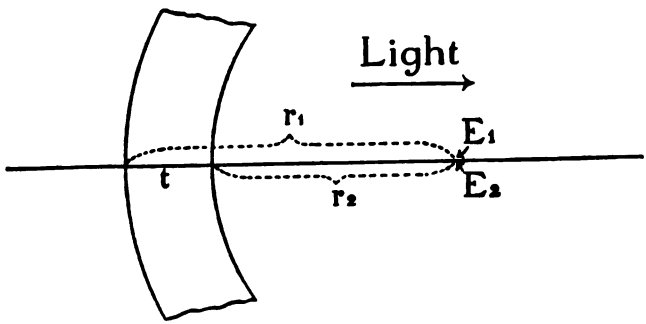


FIG. 86.

curves have a common centre. Here r_1 and r_2 have a common centre, E_1 or E_2.

$$t = r_1 - r_2, e = r, e' = -r_2$$

and $$F = \frac{\mu r_1 r_2}{(\mu - 1)r_1 - r_2} \quad \ldots\ldots \quad [56]$$

Thus let $\mu = 1{,}5$, $t = 2$, $r_1 = 10$, $r_2 = -8$. Then $N = 2$, $e = 10$, $e' = -8$, and $F = -120$, and therefore negative. Ross made a lens on this principle, obtaining a positive focus by means of the intermediate cemented curves. This concentric lens answered fairly well for copying, as it gave a very flat field, but it could not stand a large aperture. For some reason or other the firm have not entirely abandoned it, although their Homocentric is a far superior lens, and can be used for every purpose equally well.

5. *The Hypergon.*—This is a symmetrical doublet, consisting of two deeply curved menisci, each forming a hemisphere, the

two together thus forming a sphere with the diaphragm at the common centre of curvature.

In fact, it is precisely similar to my single meniscus, only with a second similar lens reversed on the other side of the diaphragm. Since all the rays are practically chief rays, it works at an enormous angle, 135°, but the aperture is small (to

FIG. 87.—Goerz Hypergon Lens. Angle = 135°. S = stop to equalize the light. F = 60.

avoid coma), viz. F/20. There is practically no astigmatism (see page 106). It is, of course, non-achromatic.

$$
\begin{array}{lll}
\text{The values are } r_1 = + 5{,}083 & & \mu_C = 1{,}508 \\
\qquad\qquad t = 1{,}324 & & \mu_F = 1{,}516 \\
\qquad\qquad r_2 = - 5{,}106 & & \\
\qquad\qquad \frac{\Delta}{2} = 4{,}070 & & \\
\qquad\qquad \mu_D = 1{,}5105 & & \\
\qquad\qquad \mu_G = 1{,}5205 & & \text{Glass No. } 0.144
\end{array}
$$

6. *The Unofocal Lens.*—If you turn to § 53 you will see that the Petzval condition places a serious limitation on the optician in the construction of lenses, for if the two lenses have the focal

lengths ϕ_1 and ϕ_2 and the refractive indices and relative dispersions are represented by μ_1 and μ_2 and ν_1 ν_2, then to form an achromatic combination we must first have

$$\frac{\phi_2}{\phi_1} = \frac{\nu_1}{\nu_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad [57]$$

and to fulfil the Petzval condition

$$\frac{1}{\mu_1\phi_1} + \frac{1}{\mu_2\phi_2} = 0, \text{ or } \frac{\phi_2}{\phi_1} = \frac{\mu_1}{\mu_2} \quad . \quad . \quad . \qquad [58]$$

FIG. 88.—Series I., F/6.

FIG. 89.—Series II., F/4,5.

Two varieties of Unofocal Lenses.

i.e. the absolute focal lengths and the pseudo-focal lengths must be identical, or

$$\frac{\nu_1}{\nu_2} = \frac{\mu_1}{\mu_2}$$

Unfortunately, the difference in refractive indices in two different glasses otherwise suitable cannot be obtained to exceed the ratio of 30 to 33. So the focal lengths must be nearly in that ratio. Now Steinheil got over this difficulty by taking a convex lens and combining it with a concave lens *of*

the same focal length and the same refractive index. And herein lies the artifice. If a very thin concave lens be placed in optical contact with a similar lens of equal focus but of opposite sign, the two lenses neutralize each other, and the result is a no-curvature lens without power. If, however, we separate the two lenses a positive power for the combination is obtained, which can be increased in proportion to the amount of separation.

Thus let A be a positive lens of 5-in. focus; B a negative lens of 5-in. focus. If in contact

$$\frac{1}{\phi} = \frac{1}{5} - \frac{1}{5} = 0.$$

If separated by 1 in.

$$\frac{1}{\phi} = \frac{1}{5-1} - \frac{1}{5} = \frac{1}{20}, \text{ or } \phi = 20 \text{ in.}$$

If separated 2 in., $\phi = 7\frac{1}{2}$ in., and so on.

By making use of this fact Steinheil not only obtains a positive combination by means of which a real image is formed, but by a careful selection of glasses he is able to make the correction for colour as well, and that in the simplest way, by means of two lenses only. By a pair of similar combinations facing each other, he obtains, in addition, an orthoscopic (rectilinear) image. Such a lens will give excellent definition over a wide angle with an aperture large enough for portraiture (F/4,5). Moreover, by selecting glasses which have a nearly even dispersive power, which several of the Jena Schott glasses possess, he can largely reduce the secondary spectrum as well. This is the principle of the Unofocal lens of Steinheil, which is made in England by Messrs. Beck.

7. *Cooke Lens* (H. Dennis Taylor).—This remarkably fine lens is manufactured by Taylor, Taylor and Hobson of Leicester, and also by Voigtländer (under the name of Triple-Anastigmat), by special licence from Cooke and Sons of York. The principle is closely allied to the Unofocal, as the following description shows.

Dennis Taylor employs three separate lenses, viz. a biconvex crown in front, and a very flat biconvex crown behind, with a biconcave flint in between and close behind the front crown. The "focal power" of the negative lens is made as nearly equal to the combined powers of the two positive lenses as is necessary to complete the flattening of the images.

In other words, if D = focal power as understood by the equation

FIG. 90.—Cooke Lens. Series III., F/6,5.

$$D = \frac{1}{r_1} - \frac{1}{r_2}$$

then $$\Sigma D = D_1 + D_2 = 0 \quad . \quad . \quad . \quad . \quad [59]$$

The constants are as follows:—

$F_D = 100$ Ratio aperture F/6,8 and F/7,7

$$\left.\begin{array}{l} r_1 = 14{,}6 \\ t_1 = 2{,}59 \\ r_2 = 101{,}3 \end{array}\right\} \text{Crown } \mu_D = 1{,}6114$$

$$\left.\begin{array}{l} \Delta_1 = 0{,}38 \\ r_3 = -\ 55{,}9 \end{array}\right\} \text{Flint } \mu_D = 1{,}5482$$

$t_2 = 0{,}46$

$r_4 = 13{,}3$

$\Delta_2 = 8{,}95$

$$\left.\begin{array}{l} r_5 = 1012 \\ t_3 = 1{,}83 \\ r_6 = 69{,}8 \end{array}\right\} \text{Crown } \mu_D = 1{,}6114$$

8. *Dallmeyer's Stigmatic Lens*—This consists of two dissimilar

FIG. 91.—Dallmeyer's Stigmatic Lens. Entire lens as used for rapid or wide-angle work.

combinations, either of which can be used alone, so that three lenses of different foci are available.

9. *Homocentric Lens.*—This fine lens is the latest product of the firm of Ross & Co. It consists of a symmetrical doublet, each half being made up of a positive and a negative meniscus separated by a slight interval. The curves are really concentric,

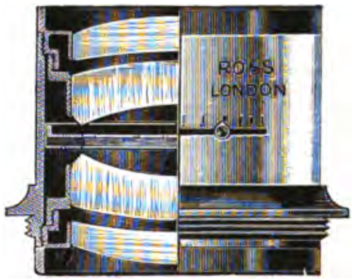


FIG. 92.—Homocentric Lens.

and possess, comparatively speaking, long radii. Each half is corrected in itself, and can therefore be used separately.

10. The *Isostigmar* (Fig. 93).—This has been recently brought out by Messrs. Beck, references to which will be found

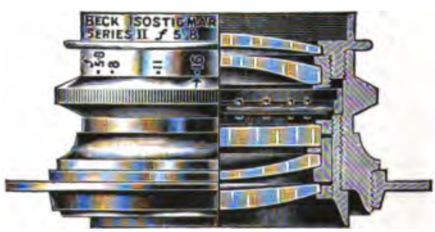


FIG. 93.—Beck's Isostigmar.

in § 38 and § 53. It is an excellent lens, and covers a large angle at the full aperture F/5,6 or F/7,7.

11. *Supplementary Lenses.*—In order to avoid the expense of buying lenses of several foci, or to be able to focus objects nearer than the camera extension will permit, supplementary lenses are sometimes added. When they are positive they shorten the focal distance, which, in the case of a fixed focus camera, is equivalent to lengthening it. If the camera is adjusted for ∞, to focus a near object all that is necessary is to

fix on to the front of the lens a supplementary lens having a focal length equal to the distance of the object from the camera and the object will be in focus. Thus, if your camera is focussed for ∞ and you wish to focus an object say 10 in. or 2 ft. or 5 ft. away, a lens of 10-in., 24-in., or 60-in. focus respectively, if added, will bring the object into focus on the screen. These lenses are single uncorrected lenses, but they do not practically affect the image unless critical definition be required, as they are fixed to the front of the corrected objective and merely converge the parallel beams entering it.

To find the equivalent focus.—For this purpose the following formula is useful:—

$$F = \frac{f_1 f_2}{f_1 + f_2 - d} \quad . \quad . \quad . \quad . \quad . \quad [60]$$

i.e. multiply the focal length of the two lenses together and divide by their sum less their distance apart, thus: Suppose the lens fixed to the camera has a focus of 6 in., the supplementary lens = 24 in. focal length, and the distance apart = 1 in. Then

$$F = \frac{f_1 \times f_2}{f_1 + f_2 - d} = \frac{6 \times 24}{6 + 24 - 1} = \frac{144}{29}, \text{or } 4\tfrac{28}{29} \text{ in.}$$

The addition of a negative lens lengthens the focus, as will be seen by changing the sign of the supplementary lens. In the above formula the combined lens will be equal to $7\frac{11}{19}$-in. focus. These supplementary lenses are not as much used as they might be, especially since a slight enlargement of the image is often very desirable. They were first introduced commercially by Mr. Conrad Beck, and are supplied by him in sets of three different foci for a very reasonable price. The Kodak Co. also supply a supplementary lens for portraiture, which can be adapted to any of their cameras.

§ 47. **Selection of a Lens.**—As a general guide to the selection of lenses the following suggestions may prove useful: *For all-round work* any of the modern Jena glass double combination lenses, either of symmetrical form or having each combination separately corrected for all aberrations, are without doubt the best, and they have the advantage that with combinations of unequal foci three focal lengths can be obtained by using either the entire lens or the front or back lens alone. The following lenses are of this type, Zeiss' Double Protar, Watson's Holostigmat, Dallmeyer's Stigmatic, Beck-Steinheil's

Orthostigmat Series II., Beck's Isostigmar, and Taylor's new Cooke Lens. The combination should have a focal length from one to one and a quarter times the longest side of the plate used.

Thus for a $\frac{1}{4}$ plate a lens from 5 to $5\frac{1}{2}$-in. focus. For a $5 + 4$ plate a lens from 6 to 7-in. focus. For a half plate the lens should be from 7 to 9-in. focal length, and for a whole plate from 9 to 12 in. Combinations in which one lens is twice as long, and the other one and a half times as long as the combined lens are very useful.

If more than one lens is used, a wide-angle symmetrical lens equal in focus to the short side of the plate, a doublet combination equal to one and a half times the longest side of the plate, and a single landscape lens, or the half of the doublet equal to twice the length of the plate used may be taken. Thus if a $5 + 4$ camera be used, the wide-angle lens should have a focus of 4 in. = angle of 64°; the doublet, a focus of $7\frac{1}{2}$ in. = angle of 37°; and the landscape lens, or half of the doublet, a focus of 10 in. = angle of 28°.

If a cheap lens be desired, a rapid rectilinear (R.R.) of a good make will do excellent work, provided it be used for a plate whose long diameter does not exceed its focal length, *i.e.* one which is used to cover an angle not exceeding 53°. But better than the rapid rectilinear is the modern Jena glass astigmat. The chief advantage of this form of lens is that it can cover a much larger plate and with a larger aperture than the older patterns. Among the cheaper forms of this type are Aldis' Series III. F/7,7, Bausch and Lomb's wide-angle and rapid Planastigmat F/6,8 and Euryplan Series III. F/7 (Staley & Co., 19, Thavies' Inn, London), Beck's new Isostigmar Series III. F/7,7, and Busch's Omnar Anastigmat F/7,7. They are certainly all excellent lenses, and, in my opinion, will answer most purposes quite as well as the more expensive ones.

For *portraiture* either a Petzval portrait lens with separable back element, or, if a flatter field be desired, any of the modern Jena glass lenses working at an intensity of F/4,5 or F/6. Such are the double anastigmat of Goerz Celor Series IB. F/4,5 to F/5,5 Staley's Euryplan F/4,5, Taylor's Cooke lens, Beck-Steinheil's Unofocal F/4,5, Beck Biplanat F/5,8, and Studio lens F/3, Dallmeyer's Stigmatic F/4, Ross' Homocentric F/5,6, Voigtländer's (triplet) Heliar F/4,5, Staley's Euryplan Series I. F/4,5, Watson's Holostigmat F/4,6, Aldis' Stigmat F/6, Zeiss'

Tessar F/3,5, Planar F/4, and Unar F/4,5. These are magnificent lenses, and there is little to choose between them. They should have a focal length at least equal to, but preferably exceeding, one and a quarter times the largest size of the plate used. In many cases a telephoto attachment may be used with great advantage, as this will have truer value and the perspective will be greatly enhanced. The Dallmeyer-Bergheim portrait lens is of low price, and gives exceedingly delicate soft pictures which appear slightly out of focus, but they are very artistic. When the lens is stopped down it gives a fairly sharp image.

Voigtländer's Portrait Lens (Series IA.) and Dallmeyer's Extra Quick-acting Portrait Lens (Series C) work at the enormous apertures of F/2,3 and F/2,2 respectively. These are probably the largest apertures which any lens can possess to be of practical value, although lenses of F/1 or thereabouts have been made, and indeed the firm of Dallmeyer advertise their willingness to make one; but for most purposes it would only be money thrown away, as it would not possess the slightest depth of focus.

For *lantern work* any of the above lenses will suit, having apertures exceeding F/5. They are preferable to the ordinary Petzval lantern objectives, owing to the much flatter field. Goerz Celor Series IB. F/4,5, the Biplanar, Unofocal, Unar, Heliar, and Anastigmat of Busch, also the Planastigmat of Bausch and Lomb, are all excellent for this purpose.

In low-power micro-photography and for kinematograph work nothing can surpass the Zeiss Planar Photographic Lenses (Series IA.) of 20 mm., 33 mm., 3-in. and 4-in. focal length; or among English makers, Beck's Orthostigmat I. of 1-in., 2-in., $2\frac{1}{4}$-in.; Watson's Holostigmat of $1\frac{1}{2}$-in., 2-in., $2\frac{1}{2}$-in., and 3-in. focal lengths, and Dallmeyer's Medallion ($1\frac{1}{2}$ in.) and Miniature Lens (3 in.), which work at F/2,2. Zeiss' Tessar (Series IIB.), and Voigtländer's Collinear and Heliar lenses are recommended by Urban, and also by Pathé Frères of Paris. They are actually superior to the usual microscopic lenses of that power, as they give equally good central definitions and a much flatter field. Most of them (below 2 in. focal length) fit on to any microscope using the Microscopical Societies' thread. For certain special work lenses of still larger aperture are made.

For *naturalistic work*, photographing wild animals, birds, and

insects, a telephoto lens is indispensable, and cameras are made by Newman & Guardia, Dallmeyer, Sanders and Crowhurst, Sinclair, Ross, and others, specially adapted for this class of work. An ordinary camera objective is usually fitted to the telephoto, provided it has sufficient aperture, so that if the photographer select one of the above-mentioned lenses working from F/4 to F/6,3, it will do for all purposes. Dallmeyer, however, prefers a portrait lens working at F/3 for the positive objective.

For *three-colour process work* semi-apochromatic lenses, which are more or less completely corrected for three colours of the spectrum, should be employed, the best colours being the orange (C656), the orange lithium line (610), the green (b_1 517), and the violet (g423). Zeiss manufactures a special apochromatic planar[1] working at F/8,3 and also a Tessar lens for this purpose; and Voigtländer an apochromatic collinear lens, which gives perfect colour correction between the lines C and G. Steinheil also makes a similar lens. Lately Rodenstock of Munich have issued an apochromatic Heligonal lens which is corrected for the secondary spectrum. It works at an aperture of F/9. These are, we believe, the only lenses in which the secondary spectrum is practically abolished, and which therefore have one focus for all colours within certain limits. Recently Watson & Sons have issued a new lens for process work called the "Actinolux" F/11, the medium being quartz, which is remarkably transparent to the ultra-violet rays. These rays are the special characteristics of the arc light, so that although it only works at F/11, it is really a very rapid lens. It is highly praised by Mr. Sanger Shepherd, and is admirably adapted for both copying and three-colour work.

A quartz lens, called an "Apoquartz Anastigmat," has recently been made by the Grande Fabrique Française de Verres de Lunelles et d'Optique, 87, Rue de Turbigo, Paris, which is transparent to the ultra-violet rays. It works at F/7,5. The construction closely resembles the Goerz Anastigmat. I have not tried it, but I am told that it is very perfectly corrected for oblique rays. Like Watson's Actinolux it is very rapid, and ought to be serviceable for process work and for portraiture in artificial light.

For *astrophotographic work.*—A specially corrected lens is

[1] See Dr. Rudolph's paper, *Photo Journal*, August, 1902. The residual chromatic aberration in this lens only amounts to 0,1 mm. for an objective of 100 mm. focus and F/8 aperture.

made by Steinheil, corrected for the line g423 and the wave length 309. But an ordinary telescopic objective can be made perfectly adaptable for celestial photography by using a yellow screen. The splendid photographs taken by Ritchey, with the great refractor of the Yerkes Observatory, were all taken through a yellow screen on isochromatic plates. He places the screen just in front of the sensitive film. Of course it increases the time of exposure, but as the image is kept fixed by clockwork motion it does not matter. Still, some astronomers prefer to have special lenses made, as has been done at the Paris Observatory, or the lenses are reversed (flint outside and slightly more separated), as has been adopted in the Thompson refractor at Greenwich. But by none of these methods are better photographs secured than by Ritchey's simple plan.

For colour photography, and for the correct light-value of open-air photography, isochromatic plates and colour screens are necessary. In the former case, colour screens of the same colour as the colour photographed must be chosen. In the latter case, yellow screens, either of different shades of yellow glass, or gelatine films dyed with aurantia and placed between two thin parallel discs of glass, are used. Lumière colour plates require a special warm pinkish orange tint, which the firm issues. Colour screens are now made by a number of firms in England, notably by Beck (Beck-Harris screen), Sanger Shepherd, The Lumière Co., Wratten and Wainwright, Houghton (Ensign screen), and by Watson. They are made in different shades of colour requiring 5, 10, or 20 times the exposure without them, but the rapidities are rarely accurately stated by the manufacturers and should never be relied on.[1] Each colour must be tested separately for the plate to be used by the purchaser, if any accurate exposure be desired.

§ 48. **Testing a Photographic Lens.**—*General Tests.*—A lens may be tested both qualitatively and quantitatively. The first method merely shows what errors exist. It will give the covering power for any aperture, and is an excellent method of determining the quality of a lens. The second method determines the extent of each error compared with an ideal lens.

[1] Those manufactured by Wratten and Wainwright are prepared on strictly scientific lines, and the author can strongly recommend them for accurate work. They are prepared under the direct supervision of Dr. Mees, which is a sufficient guarantee that they are properly standardized.

Each error can be examined in turn, and by taking the ordinates and abscissæ for each 5° from the axis a curve may be drawn by which the errors may be recorded and seen at a glance. This is a rigorously exact method, and is a favourite one with Beck, who has constructed such curves for all his lenses. Astigmatism, curvature of field, and distortion may be beautifully shown in this way. Mœssard's Tourniquet camera answers admirably for this purpose. The R.P. Society have a model which I presented some years ago for the express purpose of enabling any member to rapidly test a lens for the five Seidel aberrations by its aid. A much more elaborate and beautiful apparatus, embracing every possible requisite, has been constructed by Messrs. Beck for the School of Technology, Manchester. It is, however, too large and expensive for private use. A description of it is given in Conrad Beck's shilling handbook on the lens (R. & J. Beck, Cornhill).

For rapidly judging the quality of a lens without accessory apparatus beyond an ordinary camera, the following three tests can be confidently recommended to the amateur. If it fulfils them all satisfactorily the lens may be accepted as being of a high order of merit. These tests are especially useful as they can be applied at once, before purchasing, without any apparatus.

1. The focal length and ratio aperture being ascertained and the diaphragm opened to its fullest extent, a camera having a screen 1½ to twice the focal length in width is placed on a stand and a remote transparent incandescent lamp carefully focussed on the axis.[1] The camera is then rotated on the stand (or it may be held in the hand and turned round without using a stand) so that the image may be made to travel to the corner of the plate. If, then, on examining the image with a loupe (hand magnifier), no marked falling off of the critical sharpness of the wires of the lamp, and no flare be observed spreading out from one side of the lamp between the centre and the corner of the plate, *the lens is a good one and is free from coma.*

2. Place the camera on the stand as before and focus one or several telegraph wires at not less than 100 yards away, taking care that the wires run at right angles to one another and to the axis of the lens. If the wires which cross the axis are equally crisp and sharp throughout the length of the plate, *the lens is a good one and is free from astigmatism.*

[1] The lamp should be as far away as possible, and in any case not less than 100 times the F of the lens.

3. Focus very carefully at some small test types. Then place successively a deep spectrum blue glass (not cobalt blue), a deep yellow, an emerald green, and a ruby red glass in front of the lens. If all the glasses except the red give equally sharp images, the achromatism will be satisfactory. The red glass can hardly be expected to fulfil the test unless the lens is an apochromat. If there is any doubt confirm by the "fan" test, viz. focus the centre blade of the fan by the lens alone, expose and develop the plate. If the image of the centre card is as clear as the ones on each side the chromatic correction will be satisfactory.

There are no lenses that will stand these three tests, with a large aperture, right up to the margin of the circle of illumination without any variation of the character of the image, but if you know what a really fine lens of the same focal length and aperture will do, you can readily judge the qualities of the lens you are testing by comparison.

Test by Direct Focussing.—Another very good, but not so ready a method, is to focus a row of advertisements along a flat hoarding at a distance of about 80 to 100 times the focal length of the lens used, taking care that the hoarding is at right angles to the axis of the lens. The focussing at the centre can be accurately made by examining with a hand magnifier the aerial image obtained, by using a transparent focussing-glass or by cementing a cover slip on to the rough surface of the ground glass by means of Canada balsam. A spot or cross of ink should be made on this part to aid the eye in accommodating for this spot.

Test by Photography.—A more exact test is to cover a horizontal board equally illuminated at the end of a long room with a row of Snellen's test types, astigmatic charts and chessboard designs with sharply contrasted black and white squares (see Fig. 72). These should be placed alternately and repeated as often as the length of the board will allow. The axis of the lens must be at right angles to the board and focussed on the centre group with the largest aperture of the lens, and then repeated with the middle and smallest apertures. A photograph should then be taken with full aperture, and the negative examined. The distance from the centre at the point at which the lines become confused and ill-defined will give the tangent of half the angle of view, the focal length of the lens being known. Such a test will show the angle of critical definition

and the amount of curvature of field, the quality of central definition, the apparent amount of astigmatism and coma, and the relative intensity of light at successive distances from the centre.

Bulb and Clock-face Test.—Another test much employed by manufacturing opticians is to place the lens in a suitable holder by which it can be rotated around its nodal point (2nd equivalent point) in a vertical axis at right angles to the axis of the lens and moved to and fro along a scale. A mercury thermometer bulb and clock-face are placed in a far corner of a room and illuminated by a lamp. Behind the lens at its principal focus is a Ramsden eye-piece or focussing-glass movable along a horizontal scale (in some cases graduated ground glass is used) and the angle of critical definition is measured. The clock-face allows the astigmatism to be measured; and the image of the lamp on the mercury bulb, the spherical and chromatic aberrations. Some opticians cause the lamp, bulb, and clock-face to move together across the field of view by means of cords, others again keep them fixed and move the lens instead, as above mentioned. In all cases the image (preferably the aerial image) should be examined by means of a magnifier or focussing-glass. For special tests, see under the headings Achromatism, Spherical Aberration, Astigmatism, Focal Length, Focal Plane, Distortion, Illumination, Angle and Flare Spot.

§ 49. The following is a copy of a certificate issued by the Director of the National Physical Laboratory, which gives a good idea of the way in which a lens is examined:—

THE NATIONAL PHYSICAL LABORATORY.

CERTIFICATE OF EXAMINATION OF PHOTOGRAPHIC OBJECTIVE.

Class A.

1. *Number of Objective.*—9999, No. 10000. Registered number.

2. *Description.*—Anastigmat (Series III.), diameter 1,0 in.

3. *Maker's Name.*—Messrs. Blank, London.

4. *Size of Plate* for which the objective is to be examined.—7 in. by 5 in.

5. *Number of External Reflecting Surfaces.*—8.

6. *Centering in Mount.*—Excellent.

7. *Visible Defects*—such as striae, veins, feathers, etc.—None.

8. *Flare Spot.*—None.

9. *Effective Aperture of Stops*—

Number engraved on stop.	Effective aperture, inches.	*f* Number.	C.I. Number.[1]
No. F/6,8	0,96	7,3	½
No. 8	0,70	9,9	1
No. 11	0,52	13	2
No. 16	0,38	18	3
No. 22	0,28	25	6
No. 32	0,21	33	10
No. 44	0,17	41	16

10. *Angle of Cone of Illumination, with Largest Stop* = 80,2°, giving a circular image on the plate of 11,7 in.[2] diameter.

Angle of Cone, outside which the aperture begins to be eclipsed, with Stop C. I. No. ½ (F/6,8) = 2,5°, giving a circular image on the plate of 0,3 in. diameter.

Diagonal of the plate = 80,60 in., requiring a field of 63,40°.

Stop C.I. No. 3 (F/16) is the largest stop of which the whole opening can be seen from the whole of the plate.

11. *Principal Focal Length* = 6,96 in. Back focus or length from the principal focus to the nearest point on the surface of the lenses = 6,30 in.

12. *Curvature of the Field,* or of the principal focal surface.—After focussing[2] the plate at its centre with full aperture, movement necessary to bring it into focus for an object 1 in. from its centre = 0,00 in.; ditto for an object 2 in. from its centre = 0,00 in.; ditto for an object 3 in. from its centre = 0,00 in.; ditto for an object 4,3 in. from its centre = 0,11 in.

13. *Definition* at the centre with the largest stop; excellent. C.I. Stop No. ½ (F/6,8) gives good definition over the whole of a 7-in. by 5-in. plate.

14. *Distortion.*—Deflection or sag in the image of a straight line which, if there were no distortion, would run from corner

[1] C.I.—International Congress System.
[2] The focus is for an infinitely distant object.

to corner along the longest side of a 7-in. by 5-in. plate = 0,00 in.[1]

15. *Achromatism.*—After focussing [2] in the centre of the field in white light, the movement necessary to bring the plate into focus in blue light (dominant wave length 4420) = 0,00 in.[2] Ditto in red light (dominant wave length 6250) = 0,00 in.[3]

16. *Astigmatism.*[4]—Approximate diameter of disc of diffusion [2] in the image of a point, with C.I. Stop. No. ½ (F/6,8) at 4,3 in. from the centre of the plate = 0,1 in.

General Remarks.—An excellent wide angle, extra rapid lens, practically free from distortion.

Date of issue: February 4, 1907.

Ref. O IV., 116.

F.I S. (Signed) W. H. BROOKES,
Observer.
R. T. GLAZEBROOK,
Director, The National Physical Laboratory.

NOTE.—The following is the scale of terms used: Excellent, good, fair, indifferent, bad.

§ 50. **Tests for Aberrations of Form in a Lens.**— Perhaps the most difficult problem which can be attempted in optics is to construct a lens which shall be free from aberrations, and give a perfectly sharp image on a flat surface. In addition to errors of manufacture, there are five well-known errors of form, and at least three errors of colour to be overcome.

The errors of form are: 1, Axial Spherical Aberration; 2, Coma; 3, Astigmatism; 4, Curvature; and 5, Distortion. Each of these errors has been studied by Von Seidel, who has shown that if the sum or coefficient of the correcting terms of each = zero, then, and only then, will the image of a plane perpendicular to the axis be sharp, flat, and free from distortion. But supposing all these five sums were made equal to zero, then the form of the image would be identical in all respects with the object situated in that particular plane, and the foci would be perfectly aplanatic for monochromatic light.

[1] The sag or sagitta here given is considered positive if the curve is convex towards the centre of the plate.

[2] The focus is for an infinitely distant object.

[3] Positive if movement towards the objective, negative if away from it.

[4] The objective is supposed to be perfect in other respects.

§ 51. **Spherical Aberration.**—1. *Spherical Aberration at the Axis.*—This can be demonstrated as we have shown in § 19. If the rays from a bright object, such as a candle with a perforated card in front so as to form a disc of light, be traced to the posterior focus, they will be seen to cross one another obliquely, forming by their intersection a caustic curve, of the same nature as the curve formed by the reflection of rays inside a half-filled teacup. There is no point at which all the rays meet, but there is a spot along the axis surrounded by a diffused

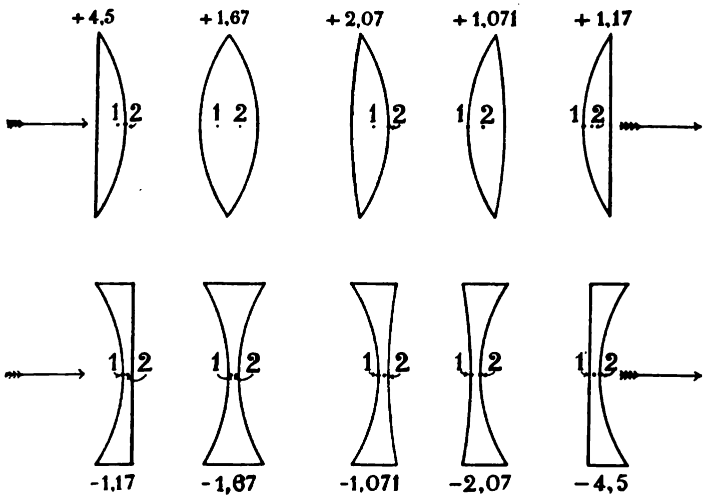


FIG. 95.—Spherical aberration of various forms of simple lenses. The numbers above and below the lenses give the amount of + or − spherical aberration. The figures 1 and 2 in the centre of the lenses refer to the 1st and 2nd principal points.

halo at which the image is brightest, which, it may be added, is further away from the lens than the spot where the cone is narrowest.

Test for Axial Aberration.—Block out the peripheral two-fifths of the diameter of the lens with a black paper ring, and focus sharply any bright object in the line of the axis.

Then remove the ring of paper and block out the middle three-fifths of the diameter of the lens, with the disc which fitted the inside of the black paper ring. If the image is not in focus, aberration is present. Another very useful test is to focus any object sharply with the full aperture. Mark the position of the screen, then stop down to a rather small aperture and

focus again. Observe whether the two positions of the screen coincide. The distance apart is a fair guide to the amount of spherical aberration.

Spherical aberration can always be diminished by using a stop, and the public are often deceived into praising the covering power of a wretched lens, owing to its having been fitted with a small permanent stop. The degree of spherical aberration in simple lenses is largely influenced by their curvature and the surface which is turned to the source of light. Fig. 95 shows the amount of spherical aberration in single lenses of various shapes as calculated by Beck. For parallel rays the aberration is least for convergent lenses when the convex side of shortest radius is turned towards the light, and the reverse in the case of concave lenses. Spherical aberration is a question of curvature rather than power. It can always be remedied by combining a + and − lens of equal spherical error, so that the excess of peripheral refraction of the convex lens is neutralized by the divergence of the concave lens.

§ 52. **The Sine Condition.**—Let L (Fig. 96) be any lens or lens system, P′P the principal axis. O an object point anywhere on the axis outside the principal focus, and I its image. Let OS be an incident paraxial ray (*i.e.* a ray nearly parallel to the principal axis), and TI the refracted ray forming the angles θ and θ' with the axis. Also let y be the linear dimensions of a *very small* vertical object, and its image y' close to I.

Let μ and μ' be the refractive indices of the media on the object side and image side of the lens.

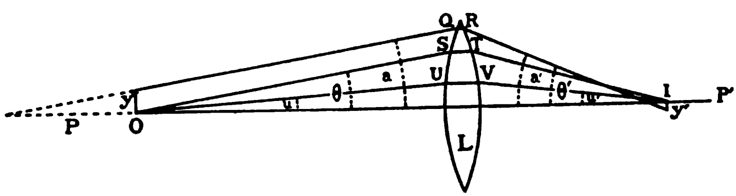


FIG. 96.—Diagram of the course of rays from an infinitely small object close to the axis.

Then it can be proved as was first shown by Lagrange that

$$\mu y\theta = \mu' y'\theta' \quad . \quad . \quad . \quad . \quad . \quad . \quad [61]$$

Since y is very small and OS a paraxial ray, θ and θ' form

PLATE IV.

FIG. 94.—Photograph of the image of a star taken with a 24-in. refractor, showing a perfectly corrected lens a little out of focus.

FIG. 99.—Appearance of coma and astigmatism together.

FIG. 98.—Appearance of high degree of coma.

FIG. 100.—Horizontal line, high degree of astigmatism.

FIG. 101.—Vertical line, high degree of astigmatism.

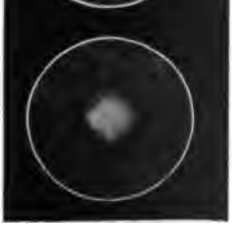


FIG. 102.—Circle of least confusion.

To face p. 136.]

very small angles. Let the ratio $\frac{y'}{y} = \beta$ the lateral magnification. Then we have

$$\frac{\sin \theta}{\sin \theta'} = \frac{\mu'}{\mu}\beta \quad . \quad . \quad . \quad . \quad . \quad [62]$$

a relation which holds true for all small values of θ and θ' (but not if the angles are large).

Now, if a lens system is so constructed that each ray directed from O to all parts of the front surface of the lens, such as OS, OU, shall meet in the point I without aberration, it can be shown that this condition will also hold true for *every part* of a minute vertical object, *e.g.* y placed *very close* to O outside the principal axis, so that if the lens be imagined to be divided up into a number of zones, USQ, etc., each zone must have the same relative magnification, or

$$\frac{\sin u}{\sin u'} = \frac{\sin \theta}{\sin \theta'} = \frac{\sin a}{\sin a'} = \kappa \text{ (a constant)}$$

This is the celebrated sine condition.

In every lens system which has a relatively large aperture compared with its focal length, the fulfilment of this condition, by which spherical aberration is eliminated, is the prime object of the optician. Owing to the great aperture required at the present day for photographic and microscopic objectives the problem has become an exceedingly difficult one.

§ 53. **Petzval Condition.**—Petzval and Coddington independently discovered, that in order to get a flat field free from astigmatism the focal length of the positive element must bear the same ratio to that of the negative element of a combination, as the refractive index of the first does to that of the second element,

$$i.e. \ \frac{1}{\mu_1 F_1} \text{ must equal } \frac{1}{\mu_2 F_2}$$

In other words, we must have

$$\frac{1}{\mu_1 F_1} + \frac{1}{\mu_2 F_2} = 0, \text{ or } \frac{F_2}{F_1} = \frac{\mu_1}{\mu_2}$$

Moreover, it is quite independent of both the thickness and amount of separation of the lenses, but in order to produce an achromatic combination, it is necessary that

$$\frac{F_2}{F_1} = \frac{\nu_1}{\nu_2}$$

ν being the index of relative dispersion, or $\frac{\mu_D - 1}{\mu_G - \mu_D}$. Thus we may combine a $+ 1$ in. with a $- 1\frac{1}{9}$ in., or a $+ 2$ in. with a $- 2\frac{1}{4}$ in., or a $+ 8$ in. with a $- 9$ in., provided always two glasses can be found to give the different ratios of dispersion expressed by the above figures. But in order to fulfil the Petzval condition, not only must the focal lengths of the two glasses bear a constant ratio to their dispersions, but they must do so to their refractive indices as well. This can be expressed mathematically by combining the two above equations so that we get

$$\frac{\nu_1}{\nu_2} = \frac{\mu_1}{\mu_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad [63]$$

Unfortunately, although there is a slight range of dispersive power, the range of the refractive indices of the glasses which are suitable for this purpose vary between the narrow limits of 30 and 33, therefore the focal lengths of the two elements must have approximately this ratio. It will be seen from this that in order to produce a lens of 10 in., one is limited to the choice of a positive element of 1 in., and a negative one of $1\frac{1}{9}$ in. Such high curves entail great expense in manufacture, and the aberrations are very difficult to correct. In fact, the condition cannot be fulfilled with the old glasses at all, if the focal lengths and refractive indices of the two elements are different, as the only way to accomplish it is by combining such diverse glasses as a light flint with a high refracting barium crown.

Steinheil, by making the positive and negative lenses of the same focal length, and of the same refractive indices, at once satisfied this condition, whatever the focal length might be, and by separation of the two elements he obtained a positive focus for the combination.

Another important property is that, if rays proceeding from any position on a flat object plane meet again at a point anywhere in the image plane, every part of the image on the axial side of this point will lie approximately in a flat plane, provided the Petzval condition is fulfilled. The Beck-Steinheil Unofocal lens is made on this principle and fulfils the condition, and it is owing to this fact that it possesses such a remarkable flat field (see Fig. 88).

NOTE.—A new lens has been invented by Messrs. Beck,

known as the Isostigmar lens, which consists of five lenses all at considerable distances from one another, which has the very remarkable quality, that, although it has a flat field absolutely free from astigmatism, it does not even approximately fulfil the Petzval condition. It is stated by the inventors that in their opinion the Petzval condition does not apply to lenses the individual elements of which are separated by large intervals. It may be noted that in the Unofocal the lenses are fairly near together.

§ 54. **Coma.**—We have just referred to the caustic curve produced by a bundle of parallel or divergent rays which meet or intersect at successive distances along the axis of an uncorrected lens. If, now, a stop be placed in front of the lens, and a candle be shifted to one side of the axis, then the oblique bundle of rays will also form a caustic curve along the focus (*i.e.* the series of focal planes), but this caustic curve differs from that of the former case in not being symmetrical with respect to the oblique pencil.

The image of the disc of the light will no longer be a bright disc with a diffuse halo of varying size round it, but a pear-shaped confused disc having at its narrow end a bright nucleus of light somewhat resembling the head of a comet. As the screen is moved further and further from the lens, the image shrinks into a line, and then broadens out into a circular patch, and this again shrinks into a straight line at right angles to the former, and finally diffuses itself into another oval. When the comet-shaped image is produced the aberration is termed Coma, and the circular patch between the lines is termed the circle of least confusion.

Test for Coma.—Place a thermometer mercury bulb (or a bright bicycle ball) at the further end of the room and illuminate it with a screened lamp, so that a small image of the lamp frame will be reflected from the bulb. Focus this on the axial line of the screen with the full opening of the lens, and then rotate the camera until the image passes to the edge of the screen. Observe whether one side of the image becomes drawn out into a pear-shaped flame.

Influence of the Diaphragm on Coma.—Let a diaphragm, having an opening, PQ, be placed in such a position that its centre, C, coincides axially with the centre, W, of the natural diaphragm in the object space, the circumference of which is formed by the lens. Then clearly all fundamental (chief) rays

which pass through R will pass without hindrance through the diaphragm PQ. But if the diaphragm be placed in any other position, some of the rays will be blocked out. The marginal rays of the cone will be represented by the line RP.

Let the distance of the centre of the diaphragm C from the pole of the lens $S_1 = e$ and let $RS_1 = W$. Let $PC = p$, and the angle $PRC = u$. Then in the triangle PRC

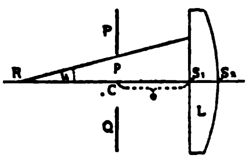


FIG. 97.

$$\tan u = \frac{p}{W - e} \quad . \quad [64]$$

by which the angle u is defined, which limits those rays which come to a definite focus on the opposite side of L from those rays which, if not blocked by the diaphragm, would fail to unite on a point and would produce coma.

Example.—Let r the radius of $S_2 = 11$ cm.; $\mu = 1{,}5$; and t, the thickness of the lens $= 2$ cm. Then

$$W = \frac{r - t}{\mu} = \frac{11 - 2}{1{,}5} = 6$$

If, therefore, we insert a diaphragm of 1 cm. radius at a distance of 3 cm. in front of the lens, then $p = 1$ and $e = 3$, so that we obtain from [**64**]

$$\tan u = \frac{p}{W - e} = \frac{1}{6 - 3} = \frac{1}{3}$$

Therefore $u = 18° 26'$, which is the limit of the coma free zone in the image plane.

§ 55. **Astigmatism.** — The above-mentioned experiment, described at the beginning of § 54, shows that any rays isolated by a stop which pass obliquely through the centre of a lens, pass through two straight lines at right angles, *i.e.* the rays form focal lines after refraction, whereas if the rays pass through the axis symmetrically they converge to a circle or point at the focal plane. It can also be shown that the greater the obliquity of the pencil, the greater the distance between the focal lines. This space between the two lines is called the *Interval of Sturm*. As the first line gradually passes into the second line, which is at right angles to it, there must be an intermediate turning-point. This is approximately a circle, and is called the "circle of least confusion," because at this spot the aberration is a minimum and consequently the definition there

is best. By the removal of radial astigmatism the two focal line images are made to coalesce so as to form a single sharp point image. But even when these radial images are converged the image plane is still curved, a fault to be dealt with under the next heading.

The formation of focal lines instead of focal points in the image is called astigmatism, but this word must not be confused with the defect astigmatism produced in the eye; although the image produced is much the same, the cause is quite different. In the former case astigmatism is produced by the caustic of *oblique* rays formed at a distance from the axis, although the curves of the lens surfaces are absolutely spherical, while central definition may be excellent. In the latter case, astigmatism is produced by the curvatures of the cornea (or crystalline) being unequal in different meridians, so that a beam of light around the principal axis is brought to a focal line instead of a focal point. Moreover, the latter defect may be corrected by means of a cylindrical lens placed at the anterior focal plane of the eye, but a lens can never be corrected by this method.

Astigmatism has been the most difficult, as well as the most important, of all the aberrations to cure, and has only been surmounted in the modern astigmat by the introduction of certain of the Jena glasses. Before these were available, all optical glass was characterized by one invariable feature: the higher the refractive index of the glass the greater was the dispersive power. As the outcome of the laboratory investigations at Jena, baryta crown glasses are now made which have the same or even higher refractive index than certain flints, of greater dispersive power, with which they can be combined.

Astigmatism has been corrected in the astigmat by placing a convex lens between two concave lenses, the convex lens having a higher refractive index than the concave lens in front of it, and a lower index than that of the other concave lens behind it. The three being cemented together, the first contact surface forms a converging and the second a diverging surface. The astigmatism is reduced by the opposition of the two cemented surfaces. It is mainly on account of its freedom from astigmatism and curvature of field that the astigmat can be used over a much wider angle and with a much larger aperture than was possible for the rapid rectilinear.

Test for Astigmatism in a Lens.—Place two black lines at

right angles, so that their image given by the lens falls on the edge of the field, or hang up at the far end of the room an ophthalmic astigmatism chart. Note the amount of racking required to get first the horizontal and then the vertical lines in focus, at measured distances from the centre. The interval between these two planes is the measure of the longitudinal astigmatic interval.

Let an assistant move a chessboard along the wall at the further end of a long room on a level with the lens, commencing from the axial line, and observe on the focussing-screen when the squares become hazy in one direction. Measure this distance. This will afford the measure of the lateral astigmatic interval.

§ 56. **Curvature of Field.**—A simple lens gives a field, not

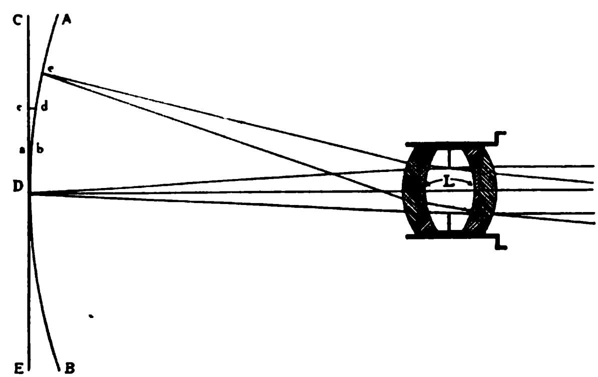


FIG. 103.

flat, but curved, with the concavity towards the lens. This is termed "Curvature of Field." Hence definition falls off towards the edge of the plate. To improve the focus at *b* or *d* (Fig. 103), the screen must be pushed towards the lens. In practice we can mark off successive intervals of say 1 in. from D to C, and measure the offsets *ab*, *cd*, at each interval. From this we can plot a curve, such as ADB, which will give the curvature.

Or we can, with the above data, calculate the curve having a radius r, from the formula

$$r = \frac{a^2}{2b} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [65]$$

in which $a =$ the distance aD, and $b =$ the distance ab, which is true when aD is small compared with LD.

When the curve has its focus directed *towards* the lens, the curvature is said to be *positive*; if *away* from the lens, the curvature is said to be *negative*.

In compound lenses the curve, if continued to the extreme edge of the plate, frequently partakes slightly of both conditions, being sinuous. If radial astigmatism cannot be got rid of, we can always diminish curvature of field in a very simple way. This consists practically in stopping down the lens, or in constructing the lens, by using what are known as anomalous glasses, that is, by combining a crown which has a less dispersion but a higher refractive index than the flint to form the achromatic combination.

The necessary condition for a flat field is that $\mu_1 F_1 = \mu_2 F_2$, F_1 and F_2 being the respective focal lengths of the crown and flint. Since $F = \frac{F_1 F_2}{F_1 + F_2}$, it is necessary for a flat field that

$$F = \frac{\mu_1 F_1}{\mu_1 - \mu_2} \quad . \quad . \quad . \quad . \quad . \quad [66]$$

But the crown must have the shorter focal length in order that the combination should have a positive focus. It follows, therefore, if we wish to satisfy the condition

$$\mu_1 F_1 = - \mu_2 F_2 \quad . \quad . \quad . \quad . \quad . \quad [67]$$

that the crown should have a higher index than the flint.

Test for Curvature of Field in a Lens.—Use the full opening. Focus an object in the centre of the field and rotate camera in until the image reaches the edge of the screen. If it can be focussed sharper by racking in, positive curvature of field is present; if sharper by racking out, the curvature is negative. The lateral distance from the centre of the focussing-glass that an object will be in focus (provided that the screen be racked in or out not more than 0,02 in.) will give the angle of sharp definition for a given size stop. A curve can be plotted out by measuring the distance through which the screen is racked in or out for each inch or half an inch from the centre.

5. *Distortion.*—This is treated under the heading of Diaphragms (§ 59).

§ 57. **Examination of other Defects connected with the Photographic Lens.**—1. *Flare Spot.*—This is caused by a

lens not only refracting, but reflecting, light incident on it, the surfaces of the elements on each side of the diaphragm acting as mirrors. Thus by successive reflections of the surfaces of the lens, an image of the brilliantly lighted out-of-focus image of the object in front of the lens may fall on the plate and there give rise to a faint circular patch of light. If the light falls perpendicularly upon the surface of a lens, the amount of light reflected can be shown to be equal to $\left(\frac{\mu - 1}{\mu + 1}\right)^2$, μ being the index of the glass. Thus, if the amount of light falling on the glass be taken as unity, and the refractive

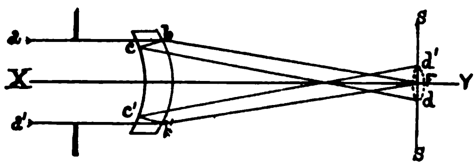


FIG. 104.

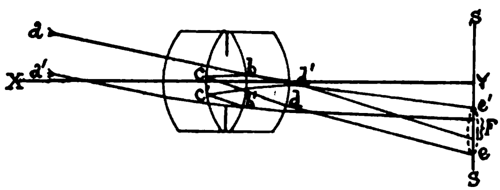


FIG. 105.

Diagrams showing how a flare spot is made by reflections from the surfaces. Fig. 104, a single lens. Fig. 105, a compound lens. The true focus is shown at F. The flare circle is formed by the rays *abcd(e)* and *a'b'c'd'(e')*. XY = principal axis.

index = 1,5, then the amount of light reflected is equal to $\left(\frac{0,5}{2,5}\right)^2 = \frac{0,25}{625} = \frac{1}{25}$, so that in this case $\frac{1}{25}$th part of the light is reflected from the surface. Consequently the second reflection will give $\left(\frac{1}{25}\right)^2$ or $\frac{1}{625}$ part of the light, an amount that will only produce a very faint image. The remedy is to shift the position of the stop or the components of the lens—a trifling amount is sometimes enough—so as to diffuse the image over the surface of the plate and thus cause it to disappear.

2. *Flare.*—Superfluous light may also reach the plate from

reflection from the brass mount, especially from the counter-screw used by some makers to fit the lens in its cell; or by internal reflections from the body of the camera, owing to the lens working at a wider angle than required to cover the plate. This may be prevented by inserting a blackened card, reaching the bellows all round, a few inches in front of the plate, and provided with a large oblong aperture which just allows the oblique rays to reach the margin of the plate. Painting bright parts with a dead black paint will often cure the flare.[1]

To test for flare, point the camera to a lamp or other bright object and throw a large cloth over the head after securing the screen and observe the reflections from the lens mount, etc. The test for the flare image should be made in a dark room while the lens is being focussed on to a gas flame. Then move the axis of the camera slightly, so as to throw the image of the

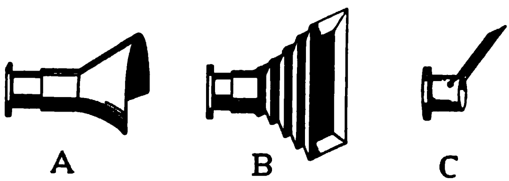


FIG. 106.—Various forms of Hoods attached to Lenses.
A, Skyshade hood; B, Detachable bellows hood, which may be extended to suit the plate; C, Flap skyshade and shutter combined, which may be set at any desired angle. The author invariably uses this form for autochrome work.

flame to one side of the centre. If flare exists an oval flare patch will be seen at the opposite side of the centre.

Another kind of flare which is inevitable in outdoor photography is due to the light entering the camera through the lens from the sky, and bright objects of all kinds which are outside the picture on the screen. This light is reflected from the body of the camera and becomes distributed over the plate. The best way to correct it is to attach a hood to the lens. Old-fashioned lenses were always provided with a hood, but this has been unnecessarily cut down in the more modern lenses. Some photographers attach a square-shaped collapsible bellows box with open ends to the front of the lens, which cuts off all the light outside the angle included in the picture (Fig. 106, B).

[1] The best dead black I know of is made by dissolving a little nitrated cellulose (cotton-wool) in acetone and then adding enough vegetable black or bone black to make a thin paste. Then paint over the bright parts with a camel's hair brush, and leave to dry.

It is often advisable when the sun is anywhere on the object-half of the sky to get some one to throw the lens into shade by means of a hat or card, the operator taking care to look at the view through the focussing-screen first, so as to make sure that the screen is not in the field of view. By this means it is possible to take a Turneresque picture with the sun directly in front. The above facts also explain why it is necessary to furnish a studio with blinds and screens on all sides in order to get the best effects of shade and contrast.

3. *Halation and Irradiation.*—This is closely akin to flare, and is due to the fact that a bright light tends to affect the sensitive salt in the film beyond the borders of its image. Thus if a photograph be taken inside a church, the boundaries of the windows will be seen bordered by halation which shows itself in the print as an ill-defined white halo. The extent of this flare increases with the intensity of the light and the darkness of surrounding parts. Hence you get it to perfection when photographing street lamps on a dark night. It is also due to another fact, viz. that the bright light penetrates the film and is reflected from the back surface of the plate on to the film again. *This is the most important cause.* It can be remedied *first* by using celluloid films which, being thin, allow of very little displacement of the reflected rays, and so render the halo too narrow to be noticed. *Secondly*, by covering the glass side of the plate with some absorbent non-reflecting material such as burnt-umber, water-colour paint, bitumen, or burnt sugar (caramel). Most photographic plate makers issue their plates already backed with such a pigment. It can be readily washed off under the tap just before development. *Thirdly*, by reversing the plate in the plate-holder as is done in the case of an autochrome plate. This is the simplest method, but unfortunately it causes lateral inversion of the image as well, which a Lumière plate does not do, because it is converted into a positive. This inversion comes out all right in carbon printing, but for ordinary printing it is obviously open to objection.

4. *Distortion of Convergence* is caused when the plate does not lie in a plane parallel with the object photographed; it is usually caused by tilting the camera upwards, for the purpose of photographing a lofty object. This causes the image of the upper portion of the object to be nearer the lens than the lower part and consequently smaller. The remedy is to raise the lens or tilt the camera as much as is necessary to include the

picture, and then to tilt the swing-back forwards until the plate is parallel to the object both vertically and laterally, when the sides of the building will also appear parallel to each other. It is advisable (but by no means absolutely necessary) to adjust the front which carries the lens, to a position parallel to the plate so as to obviate the aberrations due to oblique rays. If this cannot be done the lens should be stopped down to F/22 or less.

If a negative has been taken in which distortion of convergence is present, it can be remedied by making a transparency of the negative, and then tilting both it and the swing-back equally in *opposite* directions so as to reverse the defect until the lines are rectangular. A *very small stop* must be inserted after focussing, or the top of the picture will be out of focus. When making an enlargement a correspondingly bigger stop may be used.[1] In the same way, barrel-shaped or pin-cushioned distortion (see page 158) can be remedied in a negative by making a transparency with a lens which has a stop on the opposite side to that it had when the distortion was produced. Thus if barrel-shaped distortion is present, the transparency or bromide copy must be made with the stop placed behind the lens at a distance which will just neutralize the distortion in the negative.

5. *Exaggerated Perspective.*—This is an effect whereby objects close to the camera appear excessively large as compared with more distant ones. It occurs when a wide-angle lens is used, or when one of shorter focal length than the distance at which the picture is intended to be looked at when finished is employed, whereby objects in the foreground appear disproportionately large. The remedy is either (1) to select a lens of longer focus and at the same time to move the camera further back, (2) to use a telephoto lens, or (3) to take in less of the foreground. An enlargement made from such a negative will greatly improve the perspective since the distance at which it is looked at will be correspondingly increased. The subject will be found treated at greater length in paragraphs 70, 71, and 72.

6. *Incorrect Centering of the Lens.*—This may arise (1) from the optical centres of the components comprising a lens not lying in one straight line; (2) from the principal axis of the lens being displaced in the mount and not lying centrally.

[1] See *B. Journal Photo Almanac*, 1908, p. 950, where the whole matter is discussed.

To test if the components of a lens are centred, let the lens be accurately chucked on a lathe, and observe the reflection of a candle from the various surfaces. On rotating the lens round the principal axis the images should remain in a straight line and not undergo any movement or "wobble."

To test for the centrality of the principal axis rotate the mount; if the image of an object moves on the plate in a small circle the axis is displaced. If the lens be rotated round a vertical axis through the nodal point of emergence the images should remain still. If the lens is not perfectly centred the image will move slightly.

§ 58. **Defects of the Glass Itself.**—Small bubbles in the glass do not affect the perfection of the lens in any other way than to slightly diminish its rapidity, since the greater part

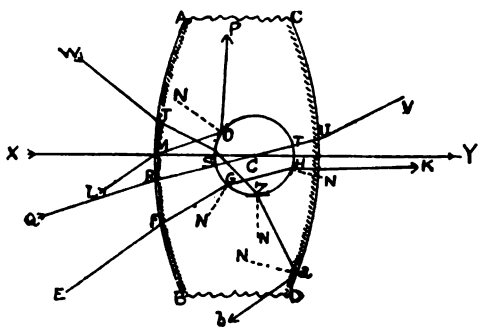


FIG. 107.—Diagram showing the passage of rays through a bubble of air in glass.

of the light impinging on it is totally reflected, and very few rays which emerge from the bubble ever pass through the lens. The avoidance is practically impossible in certain glasses where the temperature can only be raised sufficiently high in mixing to just fuse the constituents, as is the case with some of the boro-silicate Jena glasses.

Optical Effect of Air-bubbles in Glass.—Let C (Fig. 107) be the centre of a bubble; A, B, C, D portions of the surface of a lens; N, N, N, N normals to the tangents of the circumference of the bubble or lens; XY the optical axis of the lens passing through C.

The ray XY, being along the principal axis of the bubble and lens, will pass through both and emerge at Y. The ray EFG will enter the bubble at G and emerge at H. After

refraction, it will pursue the direction HK, but all rays which make an angle with the normal of the bubble exceeding 41° or 42° (the critical angle for glass) will be totally reflected. Thus the ray LM will be totally reflected from the bubble in the direction OP. Again, any other ray, such as QR, which meets the bubble at a smaller angle than 41°, and thus gains admission inside, will finally escape along the path UV, and probably miss the plate altogether. Lastly, the ray WJ will, after two refractions, emerge through the bubble at Z, only to find itself a prisoner in the glass by total reflection at *a*. Thus only a small percentage of the rays ever pass through the bubble, and still fewer ever manage to impinge on the plate. Abbe has calculated that even in the extreme cases only about 0,2 per cent. of the light is lost by reason of bubbles in the glass. In fact, the only case in which bubbles could have an injurious effect is where a large bubble or several bubbles happen to be close to the principal axis of the lens, and then only if a very small diaphragm were used. The fact that so large a percentage of light is totally reflected from the bubbles affords the explanation why they look black, since the rays are reflected at too great an angle to reach the observer's eye.

Unequal refracting effect consequent on imperfect annealing or strains can be tested for by means of the polariscope. Owing to the internal strain set up by too sudden cooling such badly annealed glass will twist light through the dark field of a polariscope and give rise to a play of colours (see "Book on the Polariscope"). Flaws and strains in the glass can be tested by Töpler's and Abbe's methods.

Discoloration may be a natural property of the glass, or it may be generated afterwards by exposure to light. If the tinge is yellow showing absorption of blue light of the spectrum, it may materially effect the rapidity of the lens. The tints assumed by various glasses can be examined by comparing over a sheet of white paper. Bad samples of balsam used in cementing may also discolour in time with exposure to light; in such cases the components must be recemented. Prolonged exposure of some kinds of glass to daylight leads to discoloration. This is probably due in some cases to a separation of the lead out of the glass. Hence the wise precaution of having caps for both ends of a lens combination, and of keeping lenses away from the direct sunlight.

§ 59. **The Diaphragm, or Stop.**—The stop in photography has three functions—

1. To increase the so-called depth of focus;
2. To equalize the illumination of the plate;
3. To reduce aberrations.

The smaller the stop the more completely will these three conditions be fulfilled.

1. The depth of focus for a constant focal length is in inverse proportion to the size of the stop, as we see from the formula given above, $X = \frac{eF}{y}$ (p. 93). The only exception is a deep meniscus lens, which, owing to its form, has an apparent greater depth of focus for the same ratio aperture than any other lens.

2. As regards the illumination of the plate, we have seen that the light falls off rapidly towards the side of the plate,

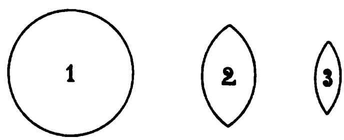


FIG. 108.—Diagram showing how the aperture appears to close up when the combinations are separated by a wide interval. 1, Circle of illumination at the axis. 2, 25° from the axis. 3, 45° from the axis.

especially when a wide-angle lens is used at its full opening. The chief cause of this is the lateral closing up of the full opening, due to the passage of the rays through the lens tube as the obliquity increases (the greater the length of tube or lens mount the more rapid being the falling off of illumination). This converts the circular aperture, as seen from the side of the screen, into a small vertical oval with pointed ends.

We know that the axial illumination is reduced in inverse ratio to the square of the aperture, but if a small stop be employed, it requires a much wider angle before any part of the circular aperture is cut off by the lens mount, so that if inequality of illumination is observed the stop should be reduced while the image is being observed under the focussing cloth, until the sides and centre appear nearly equal. If you use a lens of long focus, say one and a quarter times the width of the plate, the inequality of illumination will not matter, and the

chief trouble lies with lenses which have a focal length less than the width of the plate. Again, in photographing landscapes with a very bright sky and dark foreground the

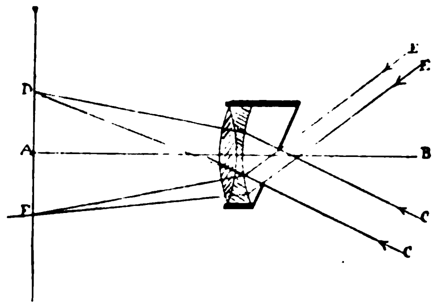


Fig. 109.—Diagram showing how a diaphragm can be adjusted to equalize the light from the sky and foreground.

illumination can, to a certain extent, be equalized by setting the diaphragm obliquely, as in Fig. 109.

It is observed that the volume of light from the foreground C, C is very much larger than that of E, E from the sky. Indeed,

Fig. 110.—Busch's Skyshade Shutter.

the stop can be set at such an angle that the amount of light from sky and foreground can actually be reversed. Care must be taken that the lens screws into the flange in the right position; but, of course, the stop can be set at any position to suit

particular circumstances. Another good method is the V stop. This consists of a small flange of black cardboard or blackened brass of a V shape, base upwards, inside the mount and a little in front of the diaphragm. Or a wedge can be cut out of a disc of cork and squeezed into the mount (Fig. 111). This gives proportionately much more light to the sides of the image as well as to the foreground. A further method is to use a flap-shutter attached to the lens mount, and hinging above it. This can be lifted up and allowed to drop by a pneumatic ball, so that any ratio of exposure one pleases can be given to the fore-ground and sky respectively (Fig. 112). Busch makes an excellent pneumatic shutter ("Skyshade Shutter"), with an up-and-down guillotine movement, which effects the same purpose. It works to time or from 1 sec. to $\frac{1}{100}$ sec. (Fig. 110). Skyshades are of great value in colour photography, especially

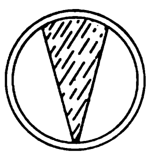


FIG. 111.

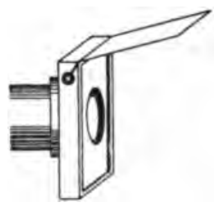


FIG. 112.—Flap form of Skyshade Shutter.

in ortochrome work, as without some such screen the skies are invariably spoilt through over exposure.

3. *For the purpose of reducing Aberrations and thereby limiting the Size of the Circles of Confusion.*—This was of far more importance in the case of lenses before the Jena glass epoch than at the present time. For not only were the lenses imperfectly corrected for spherical aberration, but landscape lenses were very largely used, which, from their construction, required a stop under all circumstances. Fig. 113 shows the effect of a stop close to the lens, and also of one at some distance away. Notice how the cone of rays is contracted in the latter case. The above fact must be borne in mind when photographing groups or objects of any kind out of doors, when the near background consists of trees showing the sky between the interstices of the leaves. Each of these spaces being out of focus will give rise to a circular diffusion patch,

which will spoil the effect of the photograph, and the larger the aperture used the larger will be the diffusion circles. If, therefore, a small stop be used (F/22 or less), this defect will almost entirely disappear (see page 150).

§ 60. **The Entrance and Exit Pupils of a Lens System.**

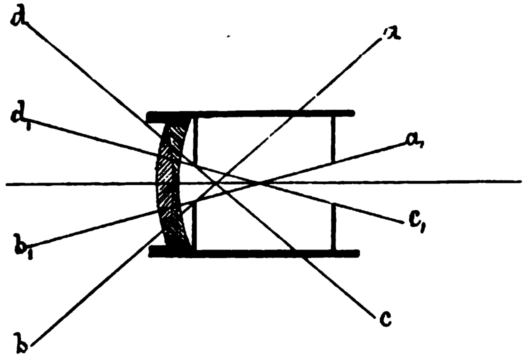


FIG. 113.

—The rays which proceed from any object and after refraction form an image, are limited in their divergence by the construction of the optical system, either by the intervention of a diaphragm, which necessarily limits the rays to the size of the aperture, or else by the margin of the lens itself, which, when

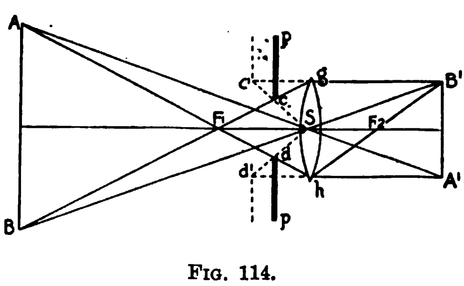


FIG. 114.

reduced in size, acts as a stop. In the latter case it becomes the boundary limit for the cone of rays, both for the object and the image. Now, consider the case where a diaphragm is placed between the object and the lens, as in Fig. 114. Here the cone of rays is limited by the hole in the diaphragm (*cd*). This diaphragm, being nearer to the lens S than its principal

focus, will have its virtual image formed on the same side of the lens, viz., at $c'd'$.

This virtual or aerial image $c'd'$ of the stop cd has been called by Abbe the "exit pupil" (Ex. P.).[1] The rays from A and B will, after refraction, meet and form image points at A′ and B′. If we produce these refracted rays gB′, hA′ backwards, they will arrive at c' and d' respectively. If we draw a line from the centre of the lens S to the margin of the diaphragm at c, it will, if produced, meet the refracted ray B′g at c', and in the same way Sd and A′h produced will meet at d'. In this way we can locate the position of the exit pupil. If we have a compound

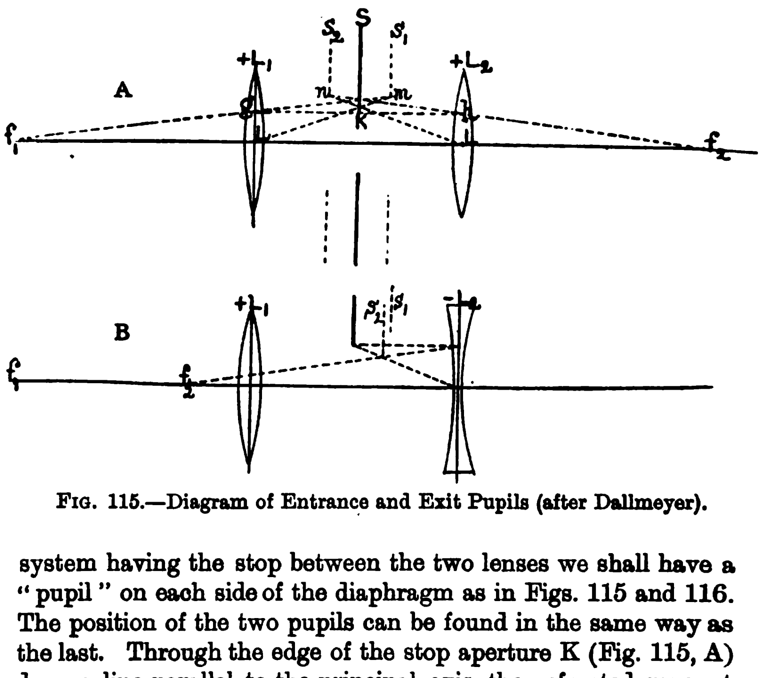


Fig. 115.—Diagram of Entrance and Exit Pupils (after Dallmeyer).

system having the stop between the two lenses we shall have a "pupil" on each side of the diaphragm as in Figs. 115 and 116. The position of the two pupils can be found in the same way as the last. Through the edge of the stop aperture K (Fig. 115, A) draw a line parallel to the principal axis, the refracted rays at g and h will therefore pass through the principal foci at f_1 and f_2. If these lines are produced backwards they will meet the lines LKm, LKn produced.

The points m and n, where the rays passing through these

[1] The author has proposed to express the words "entrance pupil" and "exit pupil" by the symbols EnP and ExP, which correspond to the German symbols EP and AP (*Eintritt Pupille* and *Austritt Pupille*).

two lenses meet, will be the margins of the ExP and EnP respectively. These pupils bear to each other the same relation that object and image do to the whole system, *i.e.* they are conjugate to one another. Moreover, all the rays which pass through the diaphagm must pass through the entrance and exit pupils, and *vice versâ*. The entrance pupil S_1m is the image of the diaphragm S_1 formed by L, and the exit pupil S_2 is the image of S formed by the second lens. In the same way in Fig. 115, B the pupil S_1 is formed by the lens L_1, and S_2 by the negative lens L_2.

It may be asked what is the use of defining these pupils? Their use is twofold. Each pupil forms the base of a triangle whose apex is at the object and image respectively, and this triangle forms the smallest cone which passes through the

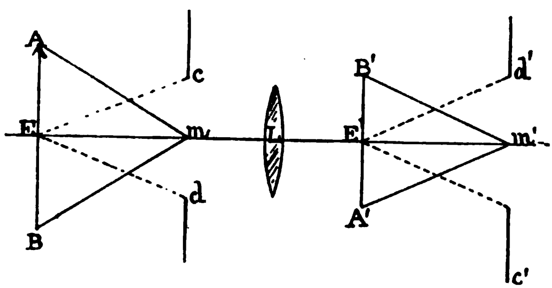


FIG. 116.

entire system (see Fig. 116). Furthermore, if the eye be placed at the centre of the EnP it will be at the exact spot from which it can view the object in correct perspective. The eye is therefore placed at the apex of a triangle whose base corresponds with the object, and in the same way if the eye be placed at the centre of the ExP, it will form the apex of a similar triangle with the image, and the eye will be at the proper distance from the image to see it in its true perspective (see Fig. 116).

Here m is the centre of perspective for the object AB and m' for the image A'B' since all points of a chief ray in the image area are conjugates of the corresponding chief rays for the object area.

§ 61. **Effective Aperture.**—When a stop is in front of a lens, the cone of light which the lens receives from a distant object is represented by the actual diameter of the stop. If, however,

as in a compound system, the stop is behind the front component, its diameter no longer gives the diameter of the beam which the lens has received, since the front component has condensed the light and enabled more to pass through the stop. (See Fig. 117 where S_1 behind the lens has the same effective value as S has in front of the lens.)

The effective value of a stop behind the front lens of a combination, is the same as if a front stop were used of the identical size of the virtual image of the stop. In the above (Fig. 117) the effective value of the stop S′S′ is really equal to the stop *pp*, which is the entrance pupil of L_1.

Thus, if the front component be of 4-in. focal length and a stop 1 in. in diameter be placed 2 in. from it, then $\frac{1}{4} - \frac{1}{2} = -\frac{1}{4}$.

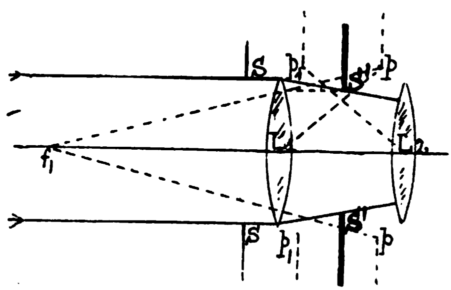


FIG. 117.

The place of the virtual image is 4 in. from the lens, and its size is $\frac{1 \times 4}{2} = 2$ in., that is, the stop has the same effect as one 2 in. in diameter placed in front of the component.

We have shown that this virtual image *pp* of the stop S′S′ (Fig. 117), in respect to the front lens, is the EnP. Similarly the diameter of the beam which emerges from the back component is represented by the ExP p_1p_1, which is the virtual image of the stop in respect to the back component.

The entrance and exit pupils would only be of the same size and at the same distance if the two components were equal, and the stop placed centrally between them.

There is no distortion in such a combination if each component is free from spherical aberration in respect to the stop and its virtual image. Thus the first component would be corrected for the stop and the EnP, and the back for the stop and ExP.

The effective aperture of a stop can be practically measured as follows: Place the lens in the camera and focus for parallel light. Replace the ground glass screen by a piece of cardboard pierced with a small hole. Place a strong light behind the cardboard. The sun is best. On holding a piece of ground glass in contact with the front lens the diameter of the disc of light which is now seen on it gives the effective aperture of the stop.

Another method of measuring the effective aperture of a stop is as follows:—

Focus a very distant bright light on the screen, then move the screen back a definite amount until the disc of light occupies a given space previously marked on the screen. The distance

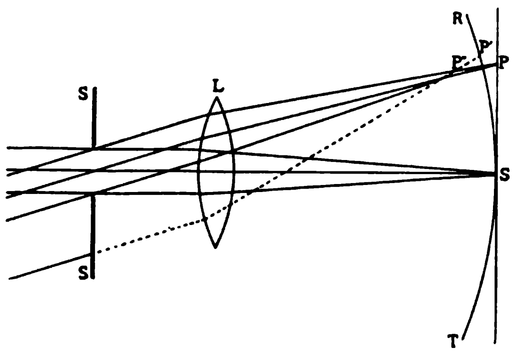


FIG. 118.

moved, divided by the space on the screen, is the effective aperture of the stop.

§ 62. **Results of Position and Size of Stop.**—A stop diminishes the effect of all aberrations except distortion, which it may increase. It decreases the lateral disc of confusion due to chromatic and spherical aberration, and decreases curvature, *i.e.* it flattens the field. By arresting oblique pencils it also diminishes coma and astigmatism. A stop is in no sense a cure for any particular aberration, it merely reduces its effect at the expense of illumination. Its effect depends in most cases on its size, but in some cases on its position.

Distortion.—When oblique light is incident on the lens L (Fig. 118) without any stop, the smallest discs of confusion lie on, or considerably in front of, the curve RS'T. By placing the stop SS a little way in front of the lens definition is not

only improved, but, since only a part of the original oblique pencils are used, the smallest discs of confusion are thrown back to P and P′ on to a plane which is approximately the focal plane. The dotted line shows the course of a ray which, had it not been for the stop, would have caused a disc of confusion or

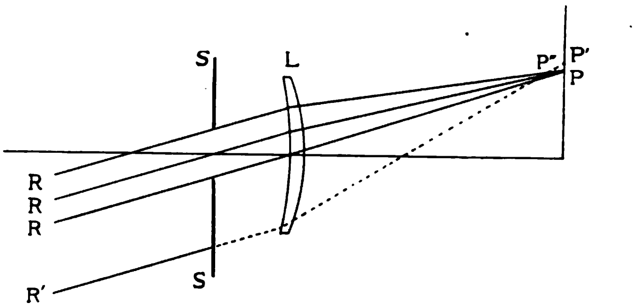


FIG. 119.—Effect of a Stop in Front of the Lens.

false focus at P′. Retiring it has the contrary effect. In the case of a single landscape lens, a stop placed about one-fourth or one-fifth of the focal length in front of it gives the best results.

A stop a short distance in front of a lens (Fig. 119) only allows those rays (RRR) which are on the *opposite side of* the

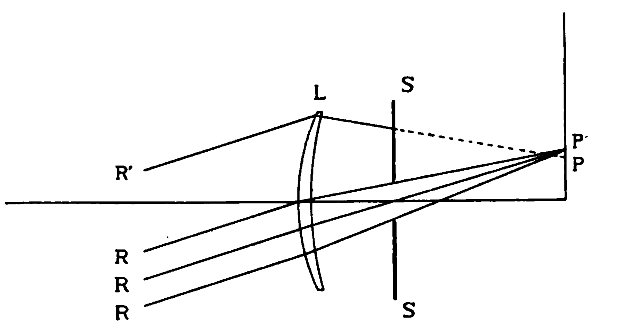


FIG. 120.—Effect of a Stop behind the Lens.

principal axis to the object to pass through the lens, the rest being blocked by the stop. The effect of this is to displace the rays inwards towards the centre of the image, thus diminishing the area of the image and producing negative or barrel-shaped distortion (Figs. 121, 3).

A stop, SS, behind a lens (Fig. 120) only allows the secondary rays (RRR) to pass through it on the *same side* of the principal axis as the object (as at P′). The effect of this is to displace the rays outwards away from the centre, thus increasing the

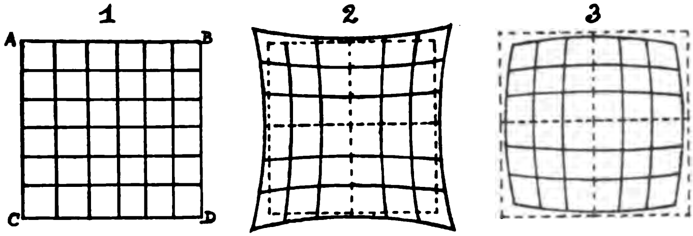


FIG. 121.

Rectilinear Object. Pincushion-shaped image of 1. Barrel-shaped image of 1.

area of the image, and producing *positive or pin-cushion* distortion. In both cases therefore the stop causes the edge of the lens to form the margin of the picture.

Since a stop in front of single combination causes negative

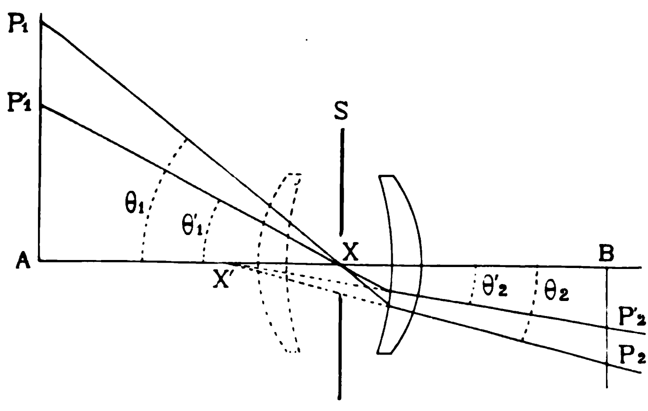


FIG. 122.

distortion, and a stop behind the same combination causes positive distortion, it is obvious that if we form a doublet by placing two identical lenses face to face with the stop midway between them, the distortion can be neutralized.

§ 63. **Tangent Condition.**—Let $P_1P'_1$ (Fig. 122) be any

points in an object placed vertically to the principal axis, and P_1X, P'_1X be two rays which pass from these points through the centre of the stop.

After undergoing refraction they will form their respective image points at P_2 and P'_2.

If these two rays be projected backwards they will meet at some point X′ on the axis. Thus X′ will be the conjugate image of X.

Let P_1X make an angle θ_1 with the axis, and P'_1 an angle θ'_1, then their refrected rays will make the corresponding angles θ_2 and θ'_2.

Let $AX = d$ and $BX' = d'$

Then $\tan\theta_1 = \dfrac{P_1A}{AX}$ or $P_1A = d \,.\, \tan\theta_1$

and $P'_1A = d \,.\, \tan\theta'_1$

also $\tan\theta_2 = \dfrac{P_2B}{BX'}$

or $P_2B = d' \,.\, \tan\theta_2$

and $P'_2B = d' \tan\theta'_2$

Now if the image is free from distortion it will be found that the angles which the object and image make with the principal angles will have a constant ratio

so that $$\frac{\tan\theta_2}{\tan\theta_1} = \frac{\tan\theta'_2}{\tan\theta'_1} = \text{a constant} \quad . \quad [68]$$

and further that the magnification, or distance between any object and the principal axis, will bear a similar ratio to the corresponding distances between the image points and axis on the image plane or

$$\frac{P_2B}{P_1A} = \frac{P'_2B}{P'_1A} = \text{a constant}$$

This is the celebrated tangent condition, which is always fulfilled if the lens is free from distortion.

Distortion is of no importance in portraiture or landscape photography, and for narrow angles of view is not noticeable in architecture. Its chief importance lies in copying maps and pictures, and in astrophotography for star measurements, in which cases a lens free from distortion is a *sine quâ non*.

When the half of a doublet is used alone the angle of view on the screen is usually only about half that of the combination,

so that the distortion at the margain of the plate is usually imperceptible. Thus the half of a modern orthostigmat, aplanat, or stigmatic lens ought to give no visible distortion of straight lines inside an angle of 35°. Even at 45° from the axis it is barely noticeable.

Although the stop is preferably circular, it may be almost any shape, as, generally speaking, its form has no effect on the image.

This may be illustrated by observing the oval patches of light on the ground under a thickly leaved tree when the sun is shining brightly nearly overhead. These oval spots or patches are the images of the apertures between the leaves. When the sun is quite overhead the spots are quite circular, yet the apertures themselves are of every possible shape.

For very critical work, such as copying pictures for process blocks, in which a finely ruled screen is e mployed to break up the image into lines and dots, it has been found that the shape of the stop affects the grain of the lines and dots. Innumerable experiments have led to the adoption of irregular shaped stops. According to Herbst a square with one quarter removed (thus) is the best form for a screen 200 lines to the inch. But the subject is too complicated to deal with here.

For certain purposes, mainly to effect the illumination of various parts of the plate, the stop may take other forms, such as the oblique stop previously mentioned, or an up-and-down guillotine shutter such as the Busch Optical Co. supply, or a flap shutter may be used (Figs. 110 and 112).

In using very wide-angle lenses, such as the Goerz Hypergon combination lens (see Fig. 87), which gives an extreme angle of 135°, a specially shaped revolving diaphragm is used to equalize the light, which would otherwise fall off considerably towards the edge of the plate. Such a lens has, however, a very limited application.

§ 64. **Numeration of Stops.**—The usual method is to number the intensity of a lens by the number of times the diameter of the stop is contained in the focal length of the lens. These are called the focal numbers (F/No.), and the proportion is called the intensity of the lens.

If, for instance, the focal length of a lens is 8 in., and the stop used is $\frac{1}{2}$ in. in diameter, its intensity is $8/\frac{1}{2}$ or F/16.

The series begins at F/2 and ends at F/64, each succeeding

stop requiring double the exposure of the one before it, F/4 being usually taken as unity. Thus—

	$\frac{F}{2}$	$\frac{F}{2,83}$	$\frac{F}{4}$	$\frac{F}{5,6}$	$\frac{F}{8}$	$\frac{F}{11,3}$	$\frac{F}{16}$	$\frac{F}{22}$	$\frac{F}{32}$	$\frac{F}{45}$	$\frac{F}{64}$
Time	$\frac{1}{4}$	$\frac{1}{2}$	1	2	4	8	16	32	64	128	256

There are other methods in use in which stops are numbered according to the relative exposures required when using them, but the one just mentioned and the following are almost universally used throughout Great Britain and the United States.

The U.S. (Uniform System) adopted by the Royal Photo-

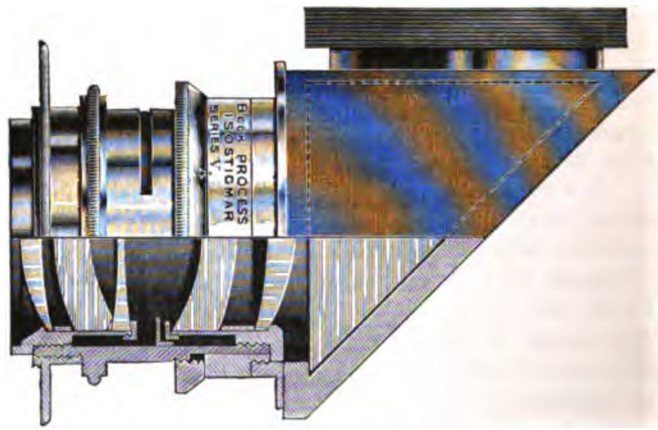


FIG. 123.

graphic Society. In this system F/4 is taken as the unit and called 1. The other stops are so numbered that the numbers indicate the relative exposures required as compared with No. 1. Thus F/5,6 = 2, F/7 = 3, F/8 = 4, requiring 2, 3, and 4 times the exposure of F/4. It is the same as the lower row given above, with the intermediate numbers filled in.

Zeiss's New System.—Here F/50 is taken as the unit, and the others numbered so that the exposure is inversely as the stop numbers. Thus F/50 = 1, F/36 = 2, F/25 = 4, etc., but I have never met any one who uses it, while his F/Nos. are only to be found on his own lenses.

$$\text{Zeiss No.} = \frac{2500}{(\text{F/No.})^2} \quad . \quad . \quad . \quad . \quad [69]$$

Dallmeyer adopted $\frac{1}{\sqrt{10}}$ or 1:3,16 as unity, so that each succeeding number, 1, 2, 3, etc., corresponds to the number of times the exposure should exceed that of a lens of F/3,16. It is ingenious, but photographers have not received it with much favour, since no one uses a lens of F/3,16.

§ 65. **Reversing Prism** (Fig. 123).—In the reproduction of drawings by mechanical means, or process photography, it is very often required to reverse the image, since, unlike an ordinary photographic print, the photographic image undergoes *two reversals* before the final print instead of one. In fact, it effects the same purpose that the second prism does in a prism binocular glass. For this purpose a rectangular (total reflection) prism is used. Its action is shown in Fig. 123A. It consists of a prism, having the sides enclosing the right angle very carefully figured. The prism is enclosed in a brass mount which screws on to the mount of the objective. The drawing to be copied is placed with its surface parallel to the axis of the objective, *i.e.* perpendicular to the plane of the focussing-screen. The rays undergo total reflection at the hypotenuse of the prism, and cross one another before reaching it, so that there is no lateral inversion. It is worth mentioning that the object to be copied must not embrace an angle exceeding 45° without taking precautions to get rid of the flare reflection from the side of the prism next to the lens, otherwise it will mar the perfection of the image. Watson has recently brought one out made of the Actinolux glass, which is highly transparent to the violet and ultra-violet rays, thereby greatly reducing the time of exposure.

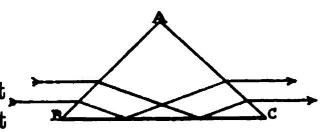


FIG. 123A.—A Reversing Prism.

CHAPTER III

THE FORMATION OF THE IMAGE ON THE SCREEN AND APPARATUS CONNECTED WITH IT

§ 66. **Magnification and Reduction.**—If we know the focal length of the lens and the magnification or reduction required, the distance of the object and image from the lens can be readily determined by the law of equivalent foci.

In Fig. 124 let L = lens, F_1 and $F_2 = F$, the anterior and posterior focal distances respectively.

Let x = distance of O from $F_1 = OF_1$;

y = distance of I from $F_2 = IF_2$;

n = number of times x is greater than F = number of magnifications;

$x + F_1 = (OF_1 + F_1) = OL = u$;

$y + F_2 = (IF_2 + F_2) = IL = v$.

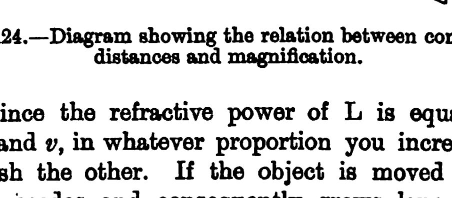


FIG. 124.—Diagram showing the relation between conjugate distances and magnification.

Then, since the refractive power of L is equally divided between u and v, in whatever proportion you increase the one you diminish the other. If the object is moved towards F, the image recedes and consequently grows larger, until OF is equal to FL, when IF will also be equal to FL, so that $u = 2F$ and $v = 2F$. This is called unit magnification, because the object and image are now of equal or "life" size. If the

object be brought still nearer the lens the image recedes and becomes larger than the object until the object arrives at F, when the image vanishes, being at infinity.

Taking our standard formula

$$F^2 = xy \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [70]$$

We find $$x = \frac{F^2}{y} \text{ and } y = \frac{F^2}{x} \quad . \quad . \quad . \quad . \quad . \quad [71]$$

Example.—The lens is 10 in. in focal length. A magnification of five times is required; where must the O and I be placed?

Since the image is to be *magnified,* I must be further away from the lens than O. The image therefore is placed

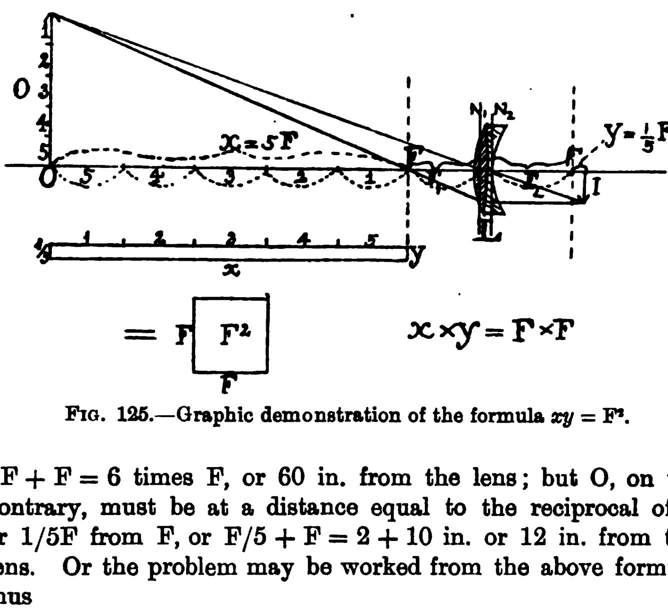


FIG. 125.—Graphic demonstration of the formula $xy = F^2$.

$5F + F = 6$ times F, or 60 in. from the lens; but O, on the contrary, must be at a distance equal to the reciprocal of 5 or 1/5F from F, or $F/5 + F = 2 + 10$ in. or 12 in. from the lens. Or the problem may be worked from the above formula thus

Since $$y = 5F, x = \frac{F^2}{5F} = \frac{100}{50} = 2 \text{ in.}$$

And as $$x = \frac{F^2}{5F}, y = \frac{F^2}{\frac{1}{5}F} = 50 \text{ in.}$$

The distance of O and I from L is therefore $2 + F = 12$ in., and $50 + F = 60$ in.

In Fig. 125 we have made a graphic illustration of this formula.

Draw a line OF $= x$, and at one end draw a short line equal in length to y. Complete the parallelogram xy. Now draw a square of which each side equals F. Then the area of the parallelogram xy will be equal to the square of $\mathrm{F} = \mathrm{F}^2$. The same result is obtained by the formula

$$\mathrm{D} = (n + 1)\mathrm{F} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [72]$$

and

$$\mathrm{D}' = \frac{n+1}{n}\mathrm{F} = \mathrm{F} + \frac{\mathrm{F}}{n} \quad . \quad . \quad . \quad . \quad [73]$$

Where D and D′ stand for distance of object and image from the lens, and n equals number of times of magnification or reduction. The above formula is often expressed by writing

$$\frac{\mathrm{I}}{\mathrm{O}} = \frac{\mathrm{F}}{\mathrm{D} - \mathrm{F}} = \frac{\mathrm{F}}{x} = \frac{y}{\mathrm{F}} \quad . \quad . \quad . \quad . \quad [74]$$

the correctness of which you can prove for yourself by working out any of the following problems with it.

Example.—A photograph is required to be reduced to one-twelfth the size, the lens being 6 in. in focus. The object must therefore be $(n + 1)$ times F from the lens $= 12 + 1$ F, or 78 in. from the lens, and the image

$$\frac{n+1}{n}\mathrm{F} = \frac{12+1}{12} \times 6 = 6{,}5 \text{ in. away from it.}$$

If the photograph were required to be enlarged twelve times, O and I would have to change places.

Suppose the lens to be 10-in. focus, and the sitter's head (9 in. long) is 12 ft. from the lens, what would be the size of the image?

The object O is 12 ft. $= 144$ in. distant, so as $\mathrm{D} = (n + 1)\,\mathrm{F}$ or $144 = 10n + 10$; $\therefore n = \dfrac{144 - 10}{10} = 13{,}4$. But the size of the image is to that of the object as their respective distances from the lens, or

$$\frac{\mathrm{I}}{\mathrm{O}} = \frac{\mathrm{D}'}{\mathrm{D}} \quad . \quad . \quad . \quad . \quad . \quad . \quad [75]$$

$$i.e. \ \frac{\mathrm{I}}{9} = \frac{\mathrm{F} + \dfrac{\mathrm{F}}{n}}{(n+1)\mathrm{F}} = \frac{10{,}75}{144}$$

and

$$\mathrm{I} = \frac{10{,}75 \times 9}{144} = 0{,}67 \text{ in.}$$

With the same lens, how far off would the camera be placed to obtain a head 3 in. long on the screen?

Since $D = (3 + 1)$ F, the answer is 40 in.

Lastly, what must be the focal length of a lens to reproduce an object one-tenth of the size, the distance being 11 ft.?

From the formula

$$D = (n + 1)\,F,\ F = \frac{D}{n+1} = \frac{132}{10+1} = 12 \text{ in.}$$

The required exposure E follows exactly the same rule. Since the time for exposure is proportional to the square of the distance of the image from the lens, we arrive at the time from the above formula for any given magnification or reduction. Thus, suppose the image, when magnified twice, needed an exposure of 30 sec., what would be the exposure necessary for a magnification of five times?

The exposure for a plate at the focal plane of the lens will be $E = \frac{30}{(2+1)^2} = 3{,}33$ sec. Hence the exposure for a magnification of five times is clearly the ratio between $(5 + 1)^2$ and $(2 + 1)^2$.

$$\text{Therefore}\quad E = \left(\frac{5+1}{2+1}\right)^2 = \frac{36}{9} = 4 \times 30, \text{ or } 2 \text{ min.}$$

or, putting another way

$$E = 3{,}33 \text{ sec.} \times (5 + 1)^2 = 120 \text{ sec.}$$

Recapitulation.

(A.) REDUCTION OF SIZE OF PICTURE.—

Let n = number of times of magnification or reduction;
D = distance of object from lens;
D′ = distance of image from lens;
E = extension of camera.

1. To find distance of lens from object, $D = Fn + F$, *i.e. multiply* F *by n and add* 1 F.

2. To find extension of camera (*i.e.* distance of image from lens), $E = \frac{F}{n} + F$, *i.e. divide* F *by n and add* 1 F.

(B.) ENLARGMENT OF SIZE OF PICTURE OR NEGATIVE.—

1. To find distance of lens from object, $D = \frac{F}{n} + F$, *i.e. divide* F *by n and add* 1 F.

2. To find distance of lens from paper or plate, $D = Fn + F$, *i.e. multiply* F *by n and add* 1 F.

(C.) EXPOSURE REQUIRED.—

$$E = (n + 1)^2 t \quad . \quad . \quad . \quad . \quad . \quad [76]$$

t being the time of exposure for a plate at F_2, *i.e. add one to the number of magnifications, square the sum, and multiply the result by the time calculated for a plate at the equivalent focus of the lens.*

NOTE.—If many pictures have to be copied, it is advisable to keep the object plane a fixture and mark the exact position of lens and screen on the table by a scale on each side of the camera,—one for magnification and one for reduction. If the same lens be used throughout, the scales will do for all time.

§ 67. **Dr. Schroeder's Method of calculating Conjugate Distances and Magnifications.**—An easy and very practical method of calculating the distances of object and image and the degree of magnification or reduction has been suggested by Dr. Hugo Schroeder,[1] which is remarkable for its simplicity.

Let D = the distance of the object in terms of the focal length of the lens, *i.e.* = number of focal lengths that the object is from the centre of the lens (anterior equivalent point) P_1;

d = distance of the image from the posterior equivalent point in terms of the focal length;

m = the number of times the image is reduced (or magnified);

m' = the number of times the image is magnified;

$e = (d - 1)$ = extension of camera beyond the ∞ plane, *i.e.* the position of screen for an object at ∞.

Then, if $D = 1$, $d = D$ divided by $D - 1$, $m = D - 1$, and $e = d - 1$.

[1] "Die Elemente der Photographischen Optik" (Oppenheim, Berlin, 1891), which contains a complete table. It is one of the best elementary books on photographic optics which exists.

$D = m + 1$	$d = \frac{D}{D - 1}$	$m = D - 1$	$e = d - 1$
1	∞	0	0
2	2	1	1
3	3/2 = 1,5	2	0,5
4	4/3 = 1,33	3	0,33
5	5/4 = 1,25	4	0,25
6	6/5 = 1,20	5	0,20
7	7/6 = 1,16	6	0,16
8	8/7 = 1,14	7	0,14
9	9/8 = 1,125	8	0,125
10	10/9 = 1,11	9	0,11

If O is at the front focus F, I will be at ∞.

If O is at two focal lengths away, I will be at the same distance behind the lens, and $m = 2 - 1 = 1$, or image and object are the same size (unit magnification).

If O is at 3 F away, I will be at $\frac{3}{2}$ F and $m = (3-1) = 2$.

If O is at 4 F away, I will be at $\frac{4}{3}$ F and $m = (4 - 1) = 3$.

Consequently, whatever the number of focal lengths the object is distant, the image is that number of F's away, divided by the same number less 1. This divisor (D − 1) gives us the number of reductions of the image.

Example.—A photograph has to be reduced to half-size. The lens is 6-in. focus. Where will the photograph be placed, and how much must we extend the camera? As the image is reduced twice, $m = 2$. But $m = D - 1$. Therefore $D = 3$, *i.e.* the object must be placed three focal lengths from the lens (or, more exactly, from E_1). The next column defines the position of the image d, since $\frac{D}{D-1} = d = \frac{3}{2}$ or 1,5. We must therefore extend our camera $1\frac{1}{2}$ focal lengths, or 9 in., *i.e.* $d - 1$, or 3 in. beyond the ∞ plane of the screen.

Since, in reduction, O is always further from the lens than I, so, in enlargement, I is always further from the lens than O. Therefore the value assigned to D in the above table is now given to d, and the value assigned to d is given to D. In other words, O and I values change places.

Example.—A picture requires enlarging $\frac{1}{5}$. $F = 6$ in. as before. Find the position of O and I. Enlarging $\frac{1}{5}$ makes the copy = 1,2. As we have to enlarge it, D becomes the distance of I from the lens, *i.e.* $D = 1{,}2 + 1 = 2{,}2 = 2{,}2 \times 6$, or 13,2 in. Also $d = \frac{D}{D-1} = \frac{2{,}2}{1{,}2} = 1{,}833$.

Therefore the object will be $6 \times 1{,}833 = 11$ in. from the nodal point of the lens.

Also $D = 2{,}2$, hence the camera must be extended $6 \times 2{,}2 = 13{,}2$ in. If you wish to prove its correctness, work it out by the standard formula $\frac{1}{F} = \frac{1}{a} + \frac{1}{b}$, in which $F = 6$ in., $a = 11$ in., and $b = 13{,}2$ in., or by our other formula $xy = F^2$. The solution in every case will be the same.

One more Example.—A half-plate camera is fitted with an 8-in. lens. How far off must a vase, 17,6 in. high, be placed so as to get the largest possible image on the plate, allowing three-quarters of an inch margin? The camera is only capable of extending $10\frac{3}{4}$ in. Can it be done? A half-plate print is $6\frac{1}{4}$ in. long when trimmed. Consequently the image must be $5\frac{1}{2}$ in. long. Now $\frac{17{,}6}{5{,}5} = 3{,}2$. Therefore $m = 3{,}2$, so that the vase must be 4,2 focal lengths away, or 33,6 in., and the camera will have to be extended to $\frac{4{,}2}{3{,}2}$, or 1,3125 times $F = 10\frac{1}{2}$ in. exactly. There is therefore $\frac{1}{4}$-in. extension to spare.

Professor Blakesley has made use of this fact in his admirable little book on Optics (Whittaker & Co., London), to find the true focal length of any lens. For each time the magnification is increased by one, the image plane is moved away from the lens through exactly one true focal distance, and each time the image is diminished by one magnification the object is moved through 1 F. If, therefore, we measure the interval through which the screen is moved to produce, say, four or five successive magnifications, and take the mean of these distances, we shall arrive at a very close estimate of the true value of F.

§ 68. **Method of making Enlargements.**—Pictures or negatives may be enlarged or reduced by means of an ordinary camera, or by employing an optical bench. The usual method is to have a camera fitted to a lantern furnished with a condenser. The negative slides into a groove at one end, close behind the condenser, the contained square of which must be slightly longer than the hypotenuse of the slide, *i.e.* if a quarter-plate negative is to be enlarged the condenser should not be less than $5\frac{1}{3}$ in. The negative should be capable of slight lateral and vertical adjustment, so as to get the desired part of the picture on to the plate, and the back of the camera should

have a swing motion both backwards and forwards, so as to correct any distortion of convergence in the negative by inclining it in the opposite direction. In this case the ground glass should be tilted until the sides are quite straight, and the plate carrier inserted in the same position. This being done, a small stop should be placed in the lens. If the distortion be caused through taking the negative with a single combination, or a landscape lens, *i.e.* if it be pin-cushion or barrel-shaped, the lens and stop should be turned round the other way, so as to produce distortion of the opposite character, the two thus neutalizing each other; when the negative may be taken as before.

In order to focus with great accuracy either Clercs' twin-diaphragm slot (Fig. 137) may be inserted between or in front of the combinations, or one of Houghton's ruled screens may be

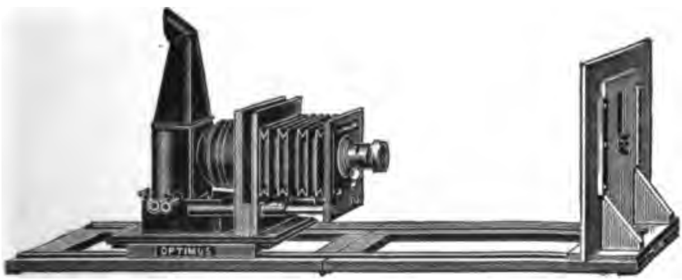


FIG. 126.—A simple form of Enlarging Easel (Perken & Son).

put in the object plane in contact with the object and the lines focussed on the plate or sensitive paper, the image being examined with a loupe. When the lens is nearly in the correct position the focussing should be performed by moving the focussing-screen and not by the lens, which should be left alone. When focus is obtained the twin diaphragm or the ruled screen is removed and the object will then be in focus.

When making lantern slides (diapositives), copies, or carbon enlargements a very slow plate should be used since the silver deposit, *i.e.* the grain of the plate, increases in coarseness with the rapidity. One should therefore use either lantern plates specially prepared for this purpose, or at any rate a "process" plate, or failing that a slow "ordinary" plate. Dry collodion plates are preferred by some. But for this purpose no plate has ever been made to beat the old wet collodion plate. For

microphotographs and coloured objects an isochromatic plate and filter screen are essential.

Where considerable magnification or reduction is required it is best to have a strongly made table provided with parallel

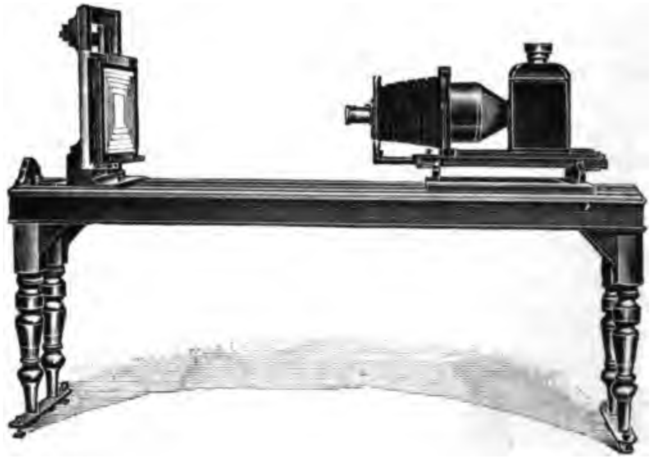


Fig. 127.—Sanders & Crowhurst's Folding Table for Enlargements and Lantern Slide making.

rails with the distance between the negative and the end of the table marked off on a scale (see Figs. 127 and 128). The

Fig. 128.—Showing the Table folded up.

space between the lens and the screen must be covered in with bellows like a camera, or, if that is not done, the source of illumination must either be outside the room, or else so covered

in that all the light passes through the lens, and thus fogging the sensitized film or paper prevented. In making bromide or carbon enlargements it is advisable to use an upright board in the place of the focussing-screen, which should be covered by a sheet of white paper. The board should be capable of being moved to and fro along the rails so as to preserve its plane parallel to the negative. When the image is as sharp as possible all over, the lens should be covered with a cap in which a piece of red or orange glass has been fitted, and the sensitized paper pinned over the focussing-sheet. The coloured image will enable the operator to adjust the bromide paper in position without fear or fog. The light which passes through the lens will not fog the sensitized paper, but scattered light may, and of course any light which reaches the paper direct without having passed through the lens is *sure* to do so. Hence in taking two pictures on one plate, half the plate may be screened off, a piece of cardboard being placed half an inch away from the plate, and still the demarcation between the two pictures will be sharp, although the light which passed through the lens covered the whole area occupied by the plate.

The time of exposure may first be ascertained by trial on a small slip of bromide paper, pinned on the focussing-sheet, and successive portions uncovered with a card for periods of $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, and 3 times the probable exposure necessary. The strip is then developed, or a trial print may be made in the printing-frame mentioned in § 97, "Practical Hints," No. 3. But preferably, and with much less trouble, either Watkins' Exposure Meter (Fig. 129) or Wynne's Sensitometer may be used, along with Dawson's Densitometer Box (Houghton & Co.). In all cases the time of exposure varies directly as the square of the distance of the image from the lens, and inversely as the square of the F/No. of the stop. The distance of the *object* makes no difference to the time of exposure.

FIG. 129.—Watkins' Bee Meter.

For the purpose of producing lateral inversion either a mirror or a reversing prism may be used (see page 163).

The source of light may be direct skylight (a window facing the north is to be preferred), or a board covered with white

blotting paper, or a sheet of white cardboard or enamelled glass should be fixed at an angle of 45° with the bottom of the negative, and the light of the sky thrown on to the negative by reflection. A mirror is not advisable, as it reflects the clouds, which cause shadows on the negative. In England daylight is so variable, that artificial light should be employed whenever it is possible. For this purpose either the arc light, limelight, acetylene light, or a single paraffin burner may be used. The mercury vapour lamp has been strongly recommended, but the tube must be very short or screened off so as to use only a very small piece of it. The light is exceedingly rich in violet rays. Many photographers place a screen of white tissue paper, or better, a fine-ground glass, just in front of the negative, *i.e.* between it and the condenser, or, as Perken & Son adopt, in contact with the front of the condenser, so as to diffuse the light more equally, which it does, but it increases the exposure by about 25 per cent., and we believe interferes with critical definition. It certainly does so in the case of microphotography. It is never advisable to have two sources of light side by side, as they give rise to blurring or even double images. This is exceedingly marked in the case of a Nernst triple-rod light when one of the side rods is not in working order, and only the central and lateral rods are incandescent. Whatever light is used, it should be single, and as *bright and small as possible*, otherwise the image will suffer in definition. All the light which passes through the condenser should come to a focus as near the equivalent point of the lens as possible. This is not essential, but by this means all the light is made use of. If this is not done the cone of light should fill the condenser and none of the light allowed to pass outside. Watson's new Actinolux lens is especially adapted for copying and process work, as the glass is highly transparent to the ultra-violet rays, which are mostly absorbed by other kinds of glass. Inasmuch as condensers are very costly and cumbersome to cover negatives larger than quarter-plate size, it is often necessary to preserve even illumination by other means for the purpose of copying large negatives, or making lantern slides from them. For this purpose Hughes has brought out his "Alphengo" enlarging lantern, which requires no condenser, and negatives of all sizes can be copied. The principle is due to the scattering of rays from two sources of light which shed the rays in all directions on to a white enamelled plate, exactly in the same way as is

done by his postcard projecting lantern. In fact this latter will answer the purpose perfectly by replacing the postcard by a sheet of white blotting paper and putting the negative anywhere between the two screens PP (Fig. 185). Perken & Son supply an excellent lens (F/5,75) for enlarging purposes (Fig. 130). It gives a brilliant and evenly lit picture, and will do equally well for lantern work, if a powerful light is used.

For copying prints or other opaque subjects two lights should be used to illuminate them if daylight cannot be used. These must be very bright—either 60-candle-power glow lamps, or gas mantles. They should be fitted with concave reflectors which increase the light thrown on the object, and screen the light from causing flare in the lens. The two lights should be on either side of the object and equally distant. If, however,

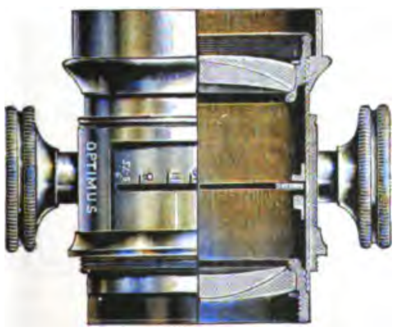


FIG. 130.—Perken & Son's Grossar Enlarging Lens.

coins or other objects have to be photographed in relief, both lights should be placed close together and very obliquely at one side, the rays making an acute angle with the plane of the object. By this means the relief may be made as prominent as you please. Be sure to remove the glass whenever possible from the picture to be copied as it acts like a mirror, and not only causes large areas of flare, but actually reproduces on the negative the objects at the back of the camera, and often the camera itself. Moreover, I have found in copying miniatures without removing the glass front, that the negative shows a series of parallel vertical diffraction bands which quite spoil the picture. The camera and the picture must therefore be arranged in such a position with regard to the light that all direct light reaching the picture is reflected away from the lens.

In other words, the lens must not be in the line of the cone of rays reflected by the picture.

§ 69. **View Finders.**—All so-called hand or snapshot cameras are fitted with some means of enabling the photographer to see whether the image is suitably placed.

This may be done in several ways.

1. *By means of a View Meter* (Fig. 131).—This consists of a frame, hinged to the end of a box having two wires crossing the centre and at a little distance a centering sight which must be in alignment with the cross wires and the eye. The size of the frame and distance of the peep-hole are managed so as to take in the same angle as the plate. This is the plan adopted in Goerz' Anschütz Camera. Where the peep-hole is in alignment with the intersection of the wires the camera is

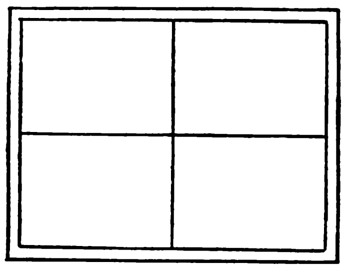


FIG. 131.

horizontal, and the plate vertical. If the camera has a rising front, the frame may be arranged to be raised to an equivalent extent, thus enabling the operator to judge of the effect of the rise of the front.

2. *By a Simple Concave Lens.*—A pair of these are often fitted into a brass ring and a plate of blackened cardboard having an oblong corresponding to the plate in shape cut out of the centre. The lenses, being circular, can be rotated to suit either a vertical or a horizontal view. Two cross lines are drawn across it with a diamond and filled in with red colour.

A peep-hole or small sighting-rod is placed at the other end of the camera, or else on a hinge an inch or so from the lens which enables the observer to bring the knob at the top of the rod in alignment with the centre of the cross lines, and thus to

avoid shifting the image with the movements of the head (Fig. 132).[1] These two finders have the advantage that the top of the camera can be held up on a level with the eye, which is not the case with the miniature camera finder next to be described. In both cases the frame may be made to be raised or lowered to correspond to the effect of the rising-front, as described in the first form.

FIG. 132.

3. *By a Camera View-finder.*—This is merely a very small camera in which the objective is replaced by a simple plano-convex or biconvex lens of great intensity (F/2) to give a brighter image. A mirror is placed at 45° at the end of the box, and the image formed by reflection on a small square of ground glass. As the image is dull notwithstanding the large aperture of the lens, the so-called brilliant view-finder has largely taken its place.

4. *By a Brilliant View-finder* (Fig. 133).—This is the invention of Adams, to whom all the improvements in this finder are due. It consists of one, or preferably two, plano-convex lenses separated by an interval, and having their convex sides towards the object (Fig. 134). The mirror is employed as before, but instead of a ground glass the image is formed just below a third plano-convex lens which replaces the ground glass.

FIG. 133.—Brilliant View-finder.

In this figure L_1 and L_2 represent the two convergent lenses, L_3 the magnifying lens, MM the plain mirror.

The rays converged by L_1 and L_2 are reflected by the mirror and come to a focus just below L_3 where the image plane is represented by an arrow. This image is real, erect, and

[1] In the latest models of the Anschütz a short-focus magnifying lens is fitted in the place of the peephole, just within its focal distance from the meter.

inverted laterally. The image that one sees is not this one, but a very slightly enlarged virtual image formed by the mirror M a little further away. It is also erect and laterally inverted. The

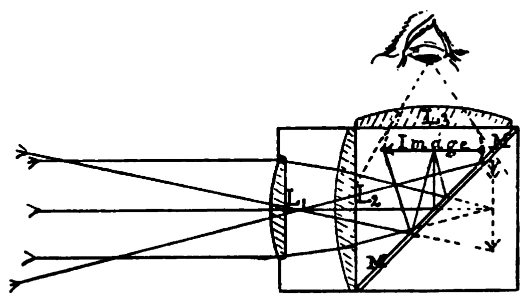


FIG. 184.

dotted arrow indicates the position the image would have if the mirror were removed. It is real inverted, as well as laterally so, and is at the common principal focus of L_1 and L_2. The image is very brilliant and does not require to be screened from the light as does the ground-glass image, but the single lens pattern is open to the objection that it shifts slightly with the movements of the observer's head. This has been overcome by the introduction of the second lens. By this means the front lens acts like the view lens of a telescope ocular and condenses the image so that more of the object can be imaged on the screen than could be done with a single lens. Moreover, the two lenses not only enable the curvature of the front lens to be reduced, but what is more important, bring the image plane close underneath the magnifying lens L_3, for it is obvious the closer the image plane lies to the lens the less is the parallax. All reflecting-mirrors cameras of necessity give rise to lateral inversion, but in a view-finder it is of no consequence, since the image is correctly represented on the plate, but if this inversion is objected to it may be got rid of by a reversing prism placed inside the view-finder, as has been done by Adams in another pattern. But I doubt if the advantage is worth paying for.

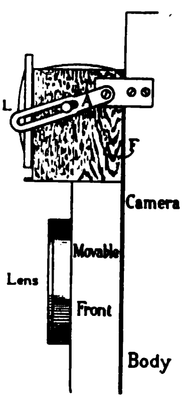


FIG. 185.—Adams' Adjustable View-finder.

The ordinary view-finder gives no indication how the rising or falling front of the camera which carries the lens affects the position of the image. Adams has ingeniously got over this difficulty by attaching a lever, A (Fig. 135), to the miniature front of the view-finder F, the other end of which is fixed on to the camera body. Since the view-finder is attached to the front of the camera, when the front is raised or lowered the view-finder F moves with it, and owing to the attachments of the lever, the front of the view-finder carrying its lens L moves up or down in exact proportion to the lens of the camera, the amount of movement in each case being strictly proportional to the focal lengths of the camera and view-finder lenses respectively.

§ 70. **Focussing.**—The ground glass used for focussing should be as fine in grain as possible, and accurately in register with the plate. In an emergency a piece of oiled tissue-paper pasted on to a piece of clean glass forms a fair substitute. Or the film may be washed off a plate and the latter rubbed over with a piece of putty, or rubbed well with fine emery, sand-paper, or pumice. A hot solution of gelatine in milk poured over a clean glass plate forms an exceedingly fine grain when dry. It is recommended for critical focussing, a second screen of clear glass being used for the final examination of the image through a magnifier.

For the finest focussing a microscope cover glass is cemented with a drop of Canada balsam on to the centre of the ground glass, on which previously a fine cross is made with a diamond or ink, and the aerial image then examined by a magnifier. The cement, by filling up the inequalities of the ground glass, renders the surface quite transparent. The object of the cross is to enable the photographer to adjust his visual accommodation for the plane of the glass, otherwise, by altering the accommodation, he might focus in a plane further from the lens than the real focal plane, since he is focussing an aerial image. A second coverslip may be affixed in the same way near each corner of the screen.

It is by no means easy to ascertain whether the image on the ground glass is the sharpest possible. If the object is dark, or indoors, and the light feeble, it is a good plan to lay a piece of white printed paper against the object and focus the type, or in the case of a portrait, for the sitter to hold the paper on the plane of the ear. The image should be examined with a magnifying lens of about 2½-in. or 3-in. focus. The best form

consists of either an achromatic lens, such as the object glass of a low-power opera glass, fixed into the top of a short tube, or else an ordinary Ramsden ocular (Fig. 136), such as is supplied with a compound microscope or telescope.

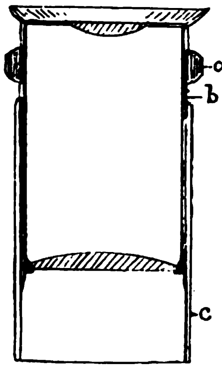


FIG. 136.—Ramsden Eyepiece, adjusted with sliding tube so as to bring the focus on to the screen. *a*, Clamping collar; *b*, Inner tube; *c* Outer tube.

Either form is arranged to slide in an outer tube, and can be fixed by a clamping collar (*a*, Fig. 136). The focusser is then placed with the outer tube flat against the outside of the screen and the lens tube clamped when the cross is in best focus.

If dark interiors have to be photographed it is a good plan to focus on some object in the middle distance with the full aperture, and then to stop down until the extreme distance is quite sharp. This will give a crisp image all over.

When photographing microscopic specimens or line drawings Clerc's twin-diaphragm slot is most useful (Fig. 137). This consists of a piece of black cardboard or metal of such a size that it will just drop into the diaphragm slot. If the lens be not provided with a Waterhouse slot, the front lens should be temporarily removed and the cardboard trimmed round so as to fit against the iris diaphragm, which should be fully opened. A circle is made with compasses the size of the full opening, and two arcs of the circle removed each a fourth of the diameter of the circle, as in Fig. 137. The stop will now have two openings. Replace the stop and lens. If now a line or a thin strand of tissue in the specimen be focussed, it will appear as a double line on the screen, which will fuse into a single line when the focus is sharp. If the lines cannot be made to coalesce the lens is defective. Fallowfield's ruled screens (Fig. 138), if put over or in the plane of a negative, will greatly facilitate critical focussing. For the purpose of examining the image a convex lens, or, better still, an achromatic Zeiss'

FIG. 137.—Clerc's Twin Diaphragm.

loupe or Ramsden eyepiece capable of adjustment is most useful. There are quite a number of patterns to be obtained at the dealers'. Houghton & Sons make a good form.

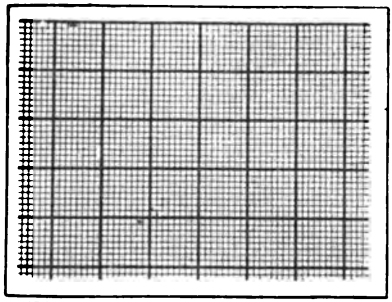


FIG. 138.

§ 71. **The Size and Shape of the Photographic Image compared with that produced by the Human Eye.**—It is frequently asked, "If the eye is a camera and the image on the retina is so minute, how is it that we see objects so very large compared with the picture obtained by the largest camera?" The following is, I believe, the correct explanation, although I have never seen it referred to in any book. We know that the size of the image is to the object as the distance of the image from the optical centre (posterior equivalent point) of the lens is to the distance of the object from the same point (or, more exactly, from the anterior equivalent point of the lens). In other words

$$\frac{\text{I}}{\text{O}} = \frac{\text{posterior conjugate distance}}{\text{anterior conjugate distance}} \quad . \quad . \quad [77]$$

Now, the eye represents a camera having a focal length of 15,5 mm. (roughly $\frac{5}{8}$ in.). Consequently a 6-in. (quarter-plate) lens gives an image about ten times as large as does the eye.

Consider the following case. A child 1 metre in height stands 50 ft. away. Compare the size of the image on the retina with a camera fitted with a 6-in. lens. Fifty feet is approximately 15,5 metres = 15,500 mm. Now $\frac{\text{I}}{\text{O}} = \frac{15{,}5 \text{ mm.}}{15{,}500 \text{ mm.}}$ or as $\frac{1}{1000}$. Consequently the retinal image of the child will be represented by a tiny spot the $\frac{1}{1000}$ of a metre, or 1 mm. high.

Since 6 in. = nearly 15,5 mm. the image on the plate will be ten times as large, or 1 cm. high. Nevertheless the child appears immense compared with the size of the child as seen in the print. Why is this?

The thing we perceive is not the inverted speck on our retina, but the image of this image projected on to the plane of the object itself. That it is not the object which we see can be readily shown. We have only to put an 8° prism base down in front of our eye, and we see the real child as before with one eye, and the projected image with the other eye, exactly the same size as the real object and identical in all respects, but slightly above it in the air.

What we see, therefore, is the mental or psychical concept of the erect virtual image of an inverted image of the object. Therefore the image we see is the same size as the negative would be, if it were to be enlarged one hundred times on an immense sheet of sensitive paper, and the print placed at a distance of 50 ft. away. A quarter-plate enlarged six times gives us a picture 2 ft. in diameter, allowing a quarter of an inch for the usual margin. If we look at this picture 5 ft. away it subtends exactly the same angle that the original negative does at the conventional near point distance of 10 in., and yet it looks at least six times as big. If therefore we enlarge the negative one hundred times, although at 50 ft., it subtends the same angle as does the image on the retina examined from the nodal point of the eye or the quarter-plate print at 6 in. away.

Again you may ask: If this explanation is correct, why do we see things magnified in a telescope or opera glass? Here the case is quite different. The telescope or opera glass is really an attachment to the eye by means of which the nodal point is removed a great deal further forward. In fact, a telescope is merely a gigantic eye in which the "cornea" is formed by the object glass of the instrument, so that when one is looking through a 6-ft. telescope one is really using an eye 6 ft. in diameter. The magnification of a telescope or opera glass may be expressed by the ratio $\frac{\omega'}{\omega}$, in which ω is the angle which the object subtends with the naked eye, and ω' the angle which the same object subtends at the image circle (just outside the eye glass) of the instrument. This is known as Abbe's definition of magnification.

If you look at the moon through a telescope and you place

a ground glass focussing-screen at the principal focus of the instrument, *i.e.* at the front focus of the eyepiece just within the tube, you will notice that this image, if viewed from a distance practically equal to the length of the telescope, is exactly the same size, and will therefore subtend the same angle as does the moon seen by the unaided eye. This may be easily proved by cutting out a disc of paper the size of the moon's image on the screen and placing it at the focal distance of the telescope objective away. It will then be found to exactly cover the moon's disc.

Suppose the telescope be 12 ft. long, or 144 in., and the near point of vision 10 in. If we examine the image on the focussing-screen, we shall see the moon under an angle $\frac{144}{10}$, or $14\frac{4}{10}$ times as great as with the naked eye. If, instead of a telescope, we turn our 6-in. camera to the moon, the disc will appear at 10 in. away, six-tenths as large as with the naked eye. If we use a 10-in. lens it will appear the same size. Hence the magnification of a lens in a camera may be expressed by the focal length of the lens in inches divided by 10 (the conventional near point of vision).

Returning to our telescope. If we view the image still nearer by looking at it through an eyepiece, we shall see the image still larger. Thus, suppose the eyepiece has a focal distance of $\frac{1}{2}$ in., then the image will appear twenty times larger than before, or 288 times as big as seen with the naked eye. This explains the meaning of the rule that the magnification of a telescope or opera glass is equal to the focal length of the object glass divided by that of the ocular, $M = \frac{F_1}{F_2}$, or, in the above case, $\frac{144}{\frac{1}{2}} = 288$ times.

A camera may at once be converted into an astronomical telescope by removing the focussing-screen and holding a little outside its plane an ordinary magnifying lens, or better still, another camera lens of shorter focus. This converts it at once into a telescope, and you may get almost any magnification you please by increasing the power of the magnifier, the only limitation being the loss of light and constriction of the size of the field. Of course, in this case, the image will be inverted. If, however, you hold a strong *concave* lens a little *within* the plane of the focussing-screen, you will make a really very efficient opera glass, and the image will be right way up. In

fact, it is quite worth while, when touring, to keep a couple of strong "short-sighted" spectacle lenses in the pocket, a $-20D$ (2 in.) and $-40D$ (1-in.) focus are perhaps the most useful. For example, supposing you have a 5×4 camera fitted with a 6-in. lens of wide aperture, all you have to do is to remove the focussing-screen and rack in an inch (if using the $-40D$ lens). Steady the wrist against the side of the camera, which is best fixed on a stand for further steadiness, and hold the lens in the former position of the camera screen, or still better, substitute a sheet of clear glass for the ground glass, and place the lens against it. You will now have an excellent monocular Galilean telescope or opera glass, having a magnification of $\frac{6}{1}$, *i.e.* six times. This is about the highest power

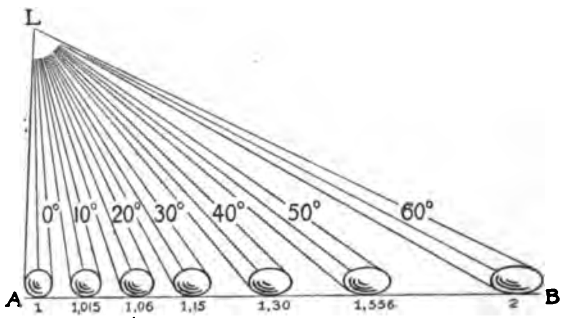


FIG. 139.

you can use with advantage. If you use the $-20D$ you must rack in 2 in., and you will get a magnification of $\frac{6}{2}$, or three times.

§ 72. **Lateral Distortion.** — If you place a number of billiard balls in a horizontal row, and focus on the centre one, you will notice they will become oval laterally as they are imaged towards the margin of the plate (Fig. 139). In fact, the oval shape (*i.e.* the proportion between the two axes of the ellipse, *i.e.* the vertical and lateral diameters) varies as the secant of the angle of obliquity. By the angle of obliquity I mean the angle which the oblique ray drawn from the optical centre of the lens and the image forms with the axis, while the secant of this angle is the length of this oblique ray in the angle ALB divided by the length of the axial ray from the optical centre to

the screen, or $\frac{LB}{LA}$. The secant is the reciprocal of the cosine, or $\frac{1}{\cos\theta}$, θ being the angle in question.

This distortion is very small for small angles, but increases very rapidly when the angle exceeds 40°. Thus, for an angle of 60°, the long diameter of the oval ball is twice the height, as will be noticed in the figure.

Thus if $\theta =$	10°	the proportion	between the	two axes	is as	1 : 1,01
	20°	,,	,,	,,	,,	1 : 1,06
	30°	,,	,,	,,	,,	1 : 1,15
	40°	,,	,,	,,	,,	1 : 1,30
	50°	,,	,,	,,	,,	1 : 1,55
	60°	,,	,,	,,	,,	1 : 2

Of course the angle θ embraces only half the plate, *i.e.* from the middle line to the side, so that in practice such extreme distortion is rare, as only lenses like Goerz' Hypergon embrace an angle of 120°. However, since a very little lateral distortion will entirely change the appearance of a person's face, it is well to avoid using wide-angle lenses when photographing groups. But for any angle under 60°, or 30° for the half-angle θ, the distortion is not noticeable, except in portraiture, for even at 30° the ratio is only 1 : 1,15, as will be seen from our table.

The above shows us the advantage in having our retina placed at *nearly* equal distances everywhere from the nodal point, by which all lateral distortion is avoided, or at least rendered imperceptible.[1]

§ 73. **Conjugate Distortion.** — This form of distortion often produces very comical results. Thus, if a horse be photographed with his head facing the lens, at a distance of a few feet, the head will be enlarged out of all proportion to the legs, which are further away. Or if a man be photographed lying down on a sofa, and the camera be placed at ten times the focal length of the lens measured from his feet, and the

[1] This is actually provided for in the case of the human eye, for we find that the centre of curvature of the retinal mirror is very nearly identical with the centre of rotation of the eye, and lies about 4 mm. behind the nodal point. Owing, however, to the peculiar construction of the crystalline lens, the retina lies in the curve formed by the centres of least confusion. The retina is, therefore, in the most favourable position possible, notwithstanding that its centre of curvature is not at the nodal point. This fact has evidently been overlooked by Dr. F. J. Allen in his paper (quoted by Bolas and Brown in their book on the "Lens," p. 122).

smallest stop be used, it will be found that when the shoes are in focus, they appear like "No. 20's," while his head is the size of an orange. Thus, suppose the man is 6 ft. in height, and his shoes 12 in. long, while his head is 9 in. The lens having 6-in. focal length, and the distance of the lens from the soles of his shoes = 7 focal lengths, or 3 ft. 6 in. Let M = number of times the image is diminished and D = distance of the object measured in focal lengths. Then

$$D = 7 \text{ and } M = 7 - 1.$$

The feet will therefore be $\frac{12}{6}$ or 2 in. long, while his head, which is 7 + 12, or 19 focal lengths from the lens, will only be $\frac{1}{18}$ of 9 in., or $\frac{1}{2}$ in. long. Consequently his feet will appear in the negative *four times the size of his head, or, compared with the latter,* 3 *ft. long.*

Now place your eye in the position of the lens and observe that the feet do not appear at all out of proportion. Let us calculate what the relative sizes really are. In this case, since 3 ft. 6 in. = 1066 mm., 6 ft. = 1830 mm., and 12 in. = 305 mm., we find $D = \frac{1066}{15{,}5}$, or 70 focal lengths, and M = 69. Consequently the feet will measure on the retina $\frac{305}{69}$ or 4,4 mm., while the head will measure $\frac{9 \text{ in.}}{69}$, or $\frac{228 \text{ mm.}}{69} = 3{,}3$ mm. in size.

In other words, while on a 6-in. camera screen, the feet appear *four times as large as the head,* in the eye, at the same distance, the feet are only *a third larger,* which is very little larger in proportion than they should be by actual measurement.

This fact also explains why, when standing in the middle of a straight road or a railway track, and looking down it, the perspective appears correct, whereas, when we examine a photograph taken in the same position with the near foreground in the picture, the road or rails appear to be spread out in an unnatural manner towards the camera, as shown in Figs. 140 and 140A.

We can now understand the immense advantage our eyes have over an ordinary camera as regards the distortion of comparatively near objects. In fact, the eye is the most perfect organ we can conceive of for the purposes for which it is used.

Its very imperfections are advantages. It is at once an autochrome camera, a kinematograph, producing life-sized coloured pictures in motion; a photometer, a stereoscope, a range-finder, a microscope, and an opera glass; while the whole apparatus is provided with a compound non-distorting rectilinear lens, working at F/4, or in some cases, F/3, and provided with a self-adjusting iris diaphragm. Helmholtz could hardly have borne these facts in mind when he stated that, had an optician made him an instrument as imperfect as the eye, he would have returned it to him. But, then, Helmholtz was ever a physicist first, and only a physiologist afterwards.

§ 74. **Shutters**.—These may be placed in front of, behind, or between the lens components, or lastly, close to the plate.

FIG. 140.—Appearance of a railway track as seen by the naked eye.

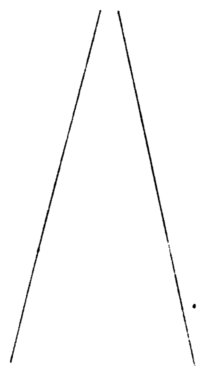


FIG. 140A.—The track as seen in a photograph taken from the same spot with an 8-in. lens.

Those in front of the lens include single- and double-flap shutters, Thornton & Picard roller-blind, the rotating wheel or sector, and to-and-fro or up-and-down shutters. They have the advantage of being quickly removed and transferred to other lenses, but they are somewhat bulky, and in the way.

Thornton & Picard's Roller-Blind Shutter is most reliable as to speed and is deservedly popular. The to-and-fro or up-and-down shutters are apt to cause vibration if actuated by a spring, and are not much used. The flap shutters can be arranged so as to give more exposure to one part of the field than another, but they again are apt to shake the camera if not carefully

handled. The Busch Optical Co. make a useful "up-and-down movement" shutter which gives about half as much exposure to the sky as the foreground.

Dallmeyer's Packard Ideal Shutter (Fig. 141) is one of the

FIG. 141.—The Packard Ideal Shutter.

best shutters of this class. It is very compact and the speed is controlled by a press ball and tube.

Shutters behind the lens.—They usually consist of a large single or double flap which opens and closes by pressing and

FIG. 142.—Dallmeyer's Central Shutter.

releasing a ball connected with a tube. They are much used in studios, since a portrait can be taken without the sitter being aware of it, but they cannot be worked much under half a second, except in the case of Dallmeyer's Central Shutter which

can be worked by hand pressure of a bulb up to the $\frac{1}{25}$ sec. (Fig. 142). This shutter may be used in front of the lens as well. It is perfectly silent, and has no trace of shake.

Shutters between the components of the lens.—Those constructed on the sector, or else the iris pattern, which open and close from the centre, give admirable definition since they act for part of the time like a small stop; at the same time they are fixtures and cannot be used for other lenses, and they admit more light to the centre of the picture than the sky and foreground. Unfortunately, they cannot be fitted to those lenses which have their combinations very close together. They are great favourites, as they are reliable and take up no room. They also work in the best possible position since all the rays

FIG. 143.—Perken's Iris Shutter.

FIG. 144.—Compound Sector Shutter.

cross one another at this spot, and the shutter therefore has the least possible distance to travel. Among those of which I have had personal experience and can thoroughly recommend are Bausch & Lomb's Unicum, Automat, and Voluteshutters, and the Koilos shutter (Zimmerman). The Compound shutter (Staley) and the Celverex (R. and J. Beck), are cheap and remarkably silent and portable. They are guaranteed accurate (?) to about five per cent. by the makers Perken & Son produce a capital little shutter called the "Iris," the speed of which is regulated by a push ball. Goerz, Zeiss, and Dallmeyer also make shutters which work between the lenses. These are superbly finished and accurate, but the price is rather high.

Shutters close to the plate.—Such is the focal-plane shutter,

which consists of a roller blind (Fig. 145) having an adjustable horizontal slit which is made to traverse the plate at a uniform speed from above downwards. As the slit can be made very narrow, and the movement of the blind can be actuated by a powerful spring, the exposure may be made very rapid, from the $\frac{1}{10}$th to the $\frac{1}{1000}$th of a second, or even higher. A focal-plane shutter is largely used in photographing rapidly moving objects, such as express trains, galloping horses, birds on the wing, etc. The spring release may be actuated by an electrically controlled magnet. It is the most effective as well as the most rapid of all shutters, but it is open to one objection which is not shared by the other kinds of shutters mentioned, viz. that it causes distortion. If the shutter moves in the same direction as the object, the latter appears lengthened. Thus a snapshot of a man jumping from a height shows his body several inches longer than it should be. To diminish this defect the shutter should be made to move in a lateral direction, when the distortion will be at a minimum. In the case of slow-moving objects the defect is not noticeable. The focal-plane shutter is one of the leading features of the Ernemann, Anshütz, and Palmos cameras. It is universally adapted to reflex cameras, and owing to its being placed so close to the plate it greatly protects the latter from the effects of reflections from the front and sides of the camera. Moreover, it does not shake the lens. These points are greatly in its favour.

FIG. 145.—Roller-blind Shutter.

Recently, Kershaw, Thornton Picard, Newman & Guardia, and Goerz have improved the focal-plane shutter by enabling the worker to regulate the size of the slit in the blind from the outside, without opening the camera; this is a great advantage and should invariably be adopted.[1]

Should exposures be required much shorter than the $\frac{1}{1500}$ sec., such as are required in photographing the splash of water, sound interference phenomena, or the motion of rifle bullets, shutters cannot be employed, but various methods may be adopted, among which are the following:—

§ 75. **Methods of Photographing the Flight of Projectiles.**—*Colonel Watkin's Method.*[2]—For this purpose Colonel

[1] Since this was written most of our leading firms have followed suit.
[2] *Proceedings of the Royal Institution*, February, 1897, p. 196.

Watkin employs a metal drum which is enclosed in a light-tight box fitted with an adjustable photographic lens of large aperture. The drum is covered with a sensitive photographic film. The lens is adjusted so that the surface of the drum shall be at the image plane. The drum is made to revolve rapidly and the speed can be ascertained, either by counting the revolutions of the wheel on the spindle outside, or by the record made by a stylus on the smoked surface of a drum outside the box, but connected with the spindle of the sensitized drum inside. In the gun or cannon is a shot filled with magnesium flashlight composition. This is electrically ignited just before the gun is fired. The lens can be focussed on any point between the muzzle and 30 ft. or so in front of it. The brilliant light issuing from the shot will impress a curved line on the film which from the known speed of the drum gives the

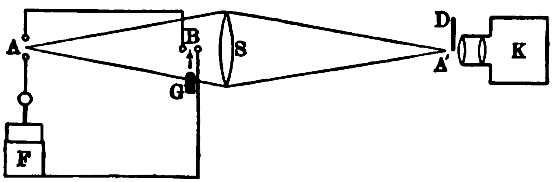


FIG. 146.

exact speed of the shot from the point at which it leaves the muzzle to 28 or 30 ft. beyond it.

Töpler's Method.—In a most ingenious way Professor Töpler has been able to demonstrate photographically the waves of compression, or strain set up in the air during the passage of a rifle bullet or by an explosion. For this purpose two small brass knobs, B (Fig. 146), are connected directly, by the lower wire with the outside of a Leyden jar, and by the upper wire (interrupted by a space, A) with the brass knob communicating with the inside of the jar. When the shot, G, is fired it touches the two knobs at B, connects the circuit, and discharges the jar, the spark passes across the two knobs at A, and illuminates the detonation wave in front of the bullet. The camera, K, is in focus for the plane at B. Covering half the lens aperture is a screen, D. If this were removed the bullet alone would be photographed, but by placing the screen in front of half the lens a diffraction image is produced which renders the

remarkable condensation waves (Knallwelle) clearly visible on the negative.

These head and tail waves are called Knallwelle or "crack" waves, because the bullet or shot in its travels carries with it a series of air waves which reach the ears of the men at the target as a sharp crack some considerable interval of time (often more than a second) before the big explosion wave arrives. In Fig. 147 three cones are visible. These are due to the condensation of the air produced by the projectile and partly to the sparking (inner plug). On close inspection of the figure three partial displacement images of the projectile can be clearly made out. These are due to the oscillation period of the spark, which from careful measurement, and knowing the rate of movement of the projectile, is found to be $\frac{1}{800000}$ sec. Thus if the displacement measures about 0,8 mm., since the shot is

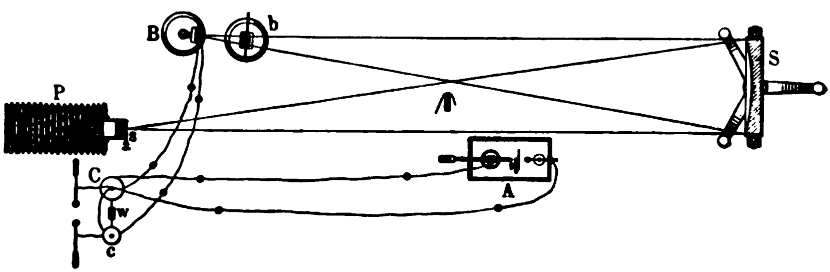


FIG. 149.

travelling 974 metres per second, the oscillation will correspond to $\frac{1}{974000} \times \frac{1}{0,8}$ or $\frac{1}{800000}$ sec. (approximately).

Mach's Method.—Instead of a lens, Professor Mach employs a concave spherical mirror of 23-ft. radius.

By means of a condensing lens, *b*, a life-size image of the spark is projected on to the diffraction screen, S, of the camera. The latter is focussed so as to form a sharp image of the projectile on the screen.

By means of the keyboard A the passage of the shot makes contact and discharges the large Leyden jar C, which sparks the battery B, and illuminates the plane of the projectile. This is an improvement over the former apparatus, since the sparking occurs after the shot has passed A, and is therefore free, so that the sparking wave does not interfere with the head and tail

PLATE V.

FIG. 147.—A blunt-nosed aluminium projectile travelling at the rate of 974 metres per second (× 2 diameters).

FIG. 148.—A near pointed brass projectile, showing head and tail waves travelling at the rate of 420 metres per second (× 2 diameters).

Both these photographs are untouched, and are reproduced here by the kind permission of Messrs. Horwitz.

To face p. 192.]

waves of the shot. Secondly, the arrangement of the sparking apparatus at B, which throws a beam through the lens on to the mirror and so back on to the shot, is a much more certain way of illuminating the object than the former method.

§ 76. **Efficiency of a Shutter.**—This signifies the ratio between the actual exposure of a shutter and that which it would give if it were at full aperture the whole time. In this case the exposure is taken as unity, and to this all shutters are compared. Since it is impossible to have the shutter fully open all the time, except in the case of flashlight exposure in a dark room, the efficiency of all shutters is expressed by a fraction. It is therefore important to bear in mind that as the efficiency diminishes, the light admitted must be proportionately increased by opening out the diaphragm. Thus, if the efficiency of the shutter is 0,5, the next larger stop should be used than the exposure tables would indicate. For example, when using an iris shutter, the efficiency of which is 0,5, if the tables give $\frac{1}{20}$ per sec. with $f/16$, one must either open the diaphragm to $f/11$ to give the correct exposure, or double the indicated exposure.

If two straight edges open from the centre of a circle and close again, the efficiency is 0,576. In the case of the iris diaphragm working between the lenses (the usual form) the efficiency is 0,33.

When a square opening crosses a circular opening, as in the so-called guillotine drop shutter, the efficiency is 0,5. When one circular opening crosses another the efficiency is 0,424.

In the focal-plane shutter the rapidity is regulated in two ways: firstly, by the tension of the spring, and secondly, by the width of the slit.[1] As we have remarked, it has the highest efficiency of any shutter. It is most important to see that no shake takes place when the shutter is released, especially in those forms in which the motion is reversed after opening to close again, as well as in some of the reflex camera shutters. Many shutters are quite worthless owing to this fault. The shutters made by Zeiss, Goerz, Newman & Guardia, Thornton Picard (Fig. 145), Bausch & Lomb, Watson, also Rodenstock's "Sector" shutter (Fig. 144), and the French "Koilos" shutter are all free from tremor, and may be relied on for workmanship,

[1] In Ross', Marion's, and some other forms of reflex cameras the tension of the spring is kept uniform, and the speed is got by altering the width of the slit. Personally, I am in favour of this method, as altering the spring gives rise to complications and uncertainty of action.

but not for indicated speed. In fact, the only shutter which can be absolutely relied on is one actuated by gravity. Those depending on a spring are bound to vary at times. Rust, dust, and grit are the chief causes of shutters "going wrong." They should, therefore, be protected as far as possible from these sources of injury. Most amateurs are apt to ignore this.

For many shutters, especially focal-plane (roller-blind) shutters, a drop of sewing machine oil will be found useful if the shutter works slower than it registers.

§ 77. **Calculation of the Slowest Speed of Shutter necessary to Photograph a Moving Object without Visible Blurring.**—Let $AB = x =$ distance travelled by the object, then $ab = y =$ distance travelled by the image on the plate.

Let u and v be the distances of O and I from the lens in

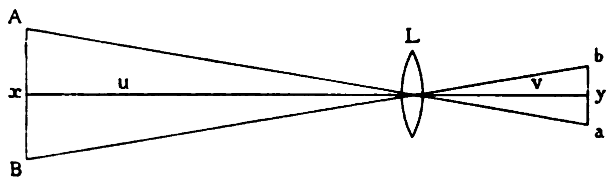


FIG. 150.

inches or centimetres, and V = velocity in inches or centimetres per second.

Then, from similar triangles

$$\frac{ab}{AB} = \frac{y}{x} = \frac{v}{u}, \text{ and } \therefore y = \frac{vx}{u} = \frac{vV}{u} \text{ in.}$$

From the fundamental formula

$$\frac{1}{F} = \frac{1}{v} + \frac{1}{u}, \text{ or } \frac{1}{v} = \frac{1}{F} - \frac{1}{u}, \text{ and } v = \frac{uF}{u - F}$$

Substituting $\frac{uF}{u - F}$ for v in the equation $y = \frac{vV}{u}$ we obtain

$$y = \frac{FV}{(u - F)} \quad . \quad . \quad . \quad . \quad . \quad [78]$$

Example.—A bicyclist is riding across the field of view at 15 miles an hour at a distance of 60 ft. from the camera. The focal length of the lens = 6 in. What is the slowest permissible

speed of the shutter, *i.e.* the diameter of the confusion circle being $\frac{1}{250}$ in. (0,1 mm.)?

$$15 \text{ miles per hour} = 22 \times 12 \text{ in. per sec.}$$

$$u = 60 \quad F = 6$$

therefore
$$y = \frac{F \cdot V}{u - F} = \frac{\frac{1}{2} \times 22 \times 12}{60 - \frac{1}{2}}$$

$$= \frac{132}{59{,}5}, \text{ or } 2{,}2 \text{ in.}$$

So that if the image moves 2,2 in. in one second the exposure must not exceed the five hundred and fiftieth of a second. If the negative is not intended for enlargement, 2ϵ or $\frac{1}{100}$ in. may be taken as the limit of confusion and a speed of $\frac{1}{220}$ of a second will suffice. In practice, where thick solid objects are photographed instead of points, we need only consider the sharpness of the margins of objects, so that we may take $\frac{1}{50}$ in. or 0,2 mm. as our limit. This renders the photograph sharp with half the above speeds, so that $\frac{1}{100}$ sec. might just do it.

Many moving objects, such as the waves of the sea or cascades should not be taken with a rapid shutter, as it gives a frozen and unnatural appearance to the water. As a rule, $\frac{1}{10}$ to $\frac{1}{25}$ sec. is quite short enough exposure.

§ 78. **To Measure the Speed of a Shutter.**—This is usually done by measuring the length of the arc formed on a plate after exposure of an object which has been caused to rotate by hand or mechanical means at a definite speed, say one revolution per second. A good plan is to turn a bicycle upside down on a low table, with the saddle and handle bars resting on it. Gum a strip of white paper round any part of the tyre, or affix a silvered glass ball anywhere under the rim, and, with a watch, turn the wheel by one of the cranks sixty times a minute. A photograph is then made, taking care that the tyre is well illuminated, and that the whole tyre is covered by the plate. Then the speed of the shutter

$$= \frac{\text{angle of arc}}{360} \times \text{speed of revolution in seconds} \quad [79]$$

Thus: A wheel revolves 100 times in 40 sec., and the angle subtended by the arc on the plate is found to be 35°; then the speed of the shutter $= \frac{35}{360} \cdot \frac{40}{100} = \frac{1}{26}$ sec. If the wheel revolves in one second the speed is $\frac{35}{360} = \frac{1}{10}$ sec.

Another plan is to drop a polished steel ball, or better, one of the silvered glass balls used on Christmas-trees, in front of a black background, starting from zero of a centimetre scale marked in white lines down the background. The ball should be well illuminated. If the shutter attached to the camera be released the moment the ball is let fall, a streak corresponding to the time of exposure will appear on the developed plate. Suppose the streak begins opposite the 3 cm. line and ends at 18 cm.

Let $t' =$ time the ball took to descend from zero to 3 cm.;
$t =$ time the ball took to descend from zero to 18 cm.

Then $t - t'$ is the time it took to travel from the 3 cm. mark to the 18 cm. mark.

Using the formula $S = \frac{1}{2}gt^2$ . . . . **[80]**

where S stands for spaee traversed and g for gravity (32,2 ft. per sec.).

we have $S = 3$

and $\frac{g}{2} = 16{,}1$ ft. $= 495$ cm.

$$\therefore t' = \sqrt{\frac{3}{495}} = \frac{1}{12{,}6}$$

In the same way, since $S' = 18$ cm., we have

$$t = \sqrt{\frac{18}{487}} = \frac{1}{5{,}2}$$

$$\therefore t - t' = \frac{1}{5{,}2} - \frac{1}{12{,}6} = \frac{1}{9} \text{ (approx.)}$$

so that the speed of the shutter $= \frac{1}{9}$ sec.[1]

Other methods depending on the vibrations of a tuning fork (Steinheil and Koch), or a gas flame in a glass tube of measured length (von Behn's method), have been recommended.

Thus let a small convex mirror be attached to one of the arms of a tuning fork placed upright on a table and a beam of light concentrated on it. If now the fork be struck and a snap-shot be taken, the camera being slightly moved in a vertical plane, the plate on development will show a number of curves corresponding to the vibrations. Supposing sixteen curves are noticed, and the note of the fork corresponds to the middle C (512 vibrations per second) the exposure will be equal

[1] Watson & Son and Beck, among other opticians, undertake to find the various speeds of any shutter for a small fixed fee.

PLATE VI.

FIG. 151.

FIG. 152.—Sir William Abney's apparatus for determining the speed of a shutter.

(By permission of the inventor.)

To face p. 197.]

to $\frac{16}{512}$, or $\frac{1}{32}$ sec. Sir W. Abney has designed an apparatus which not only gives the speed of the shutter but indicates the efficiency as well (Figs. 151, 152). He adjusts the shutter a little in front of the lens, allowing the light to pass through a narrow horizontal slit placed against the lens, which light is received upon a revolving drum covered with bromide paper, the movement of the drum being at right angles to the slit. A wheel having six spokes and thirty-six holes around the rim is made to revolve at a known speed by a motor, the speed being checked by blowing against the holes with a pitch pipe and ascertaining the note produced. Supposing the note given was E, or 640 vibrations per second, the number of holes passed through the beam was $\frac{640}{6}$, or 107 per second. The time of opening was two intervals between the passage of the spokes, or 0,023 per second, of closing 0,04 sec., and for full aperture 0,032 sec., the total time being 0,095 sec. = $\frac{1}{10}$ sec. The area of the figure may be taken as equal to six and a quarter spoke intervals. Had the shutter been a theoretically perfect one, the interval would have been ten and a quarter intervals. The efficiency therefore = 0,64.

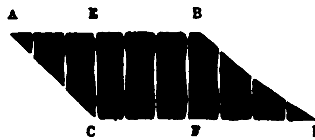


FIG. 153.—Time and Efficiency Record of the Opening of a Shutter, taken by Sir W. Abney's apparatus (Fig. 152).

§ 79. **Artificial Illumination: Flashlight Photography.** —This, in some form or other, is necessary for photographing groups at night, or taking views in mines, etc. The apparatus generally consists of a naked spirit flame, attached to which is a receptacle containing either magnesium powder or, preferably, a mixture of powdered magnesium and some oxygen-holding compound. The simple magnesium powder is blown through the flame by a puff of air generated by a rubber ball or a force-pump attached to a flexible tube. The oxygen mixture is usually placed in a heap on a dish and ignited, as it is dangerous to use a blow through apparatus owing to the tendency of the flame to flash back and ignite the rest of the powder behind. There are a large number of such contrivances in the market. Those invented by Gaederke and Miethe, and Meydenbauer, have a large sale in Germany. The Agfa flashlight powder and Dega electro-flash (Zimmermann & Co.) are popular in England. They supply a special apparatus with each.

Professor Cohn of Breslau employs a very simple and effective apparatus (Fig. 154) for photographing the exterior of the eye, by which the dilatation of the pupil in the dark can be readily shown, since the duration of the flash is too rapid for any contraction of the pupil to occur. The magnesium powder is placed in the little funnel which is closed by a lid above, and a sudden pressure of the bulb discharges it through the flame. He uses about 6 or 7 grammes (90 to 100 grains). This is sufficient for 3 or 4 exposures.

The following mixtures are recommended as being superior to simple magnesium powder, which is rather slow in action, but they must be ignited by the application of a flame and not

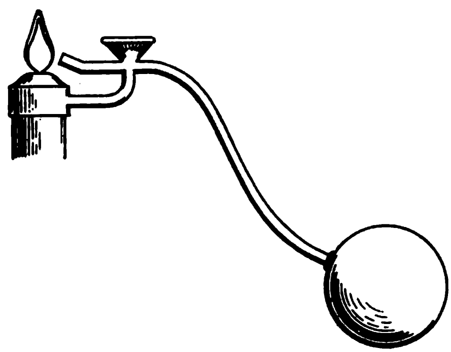


FIG. 154.—Cohn's Flashlight Apparatus.

by a blow through tube, and care must be taken to keep the face and hands well away from the flame, as the heat generated is enormous.

> Powdered magnesium, 1 part,
> Chlorate of potash, 1 to $1\frac{1}{2}$ parts.

This is excellent for groups.

For taking children and animals, which are liable to move, the following mixture is recommended :—

> Chlorate of potash ($KClO_3$), 1 part,
> Perchlorate of potash ($KClO_4$), 1 part,
> Powdered magnesium, 4 parts.

or

> Perchlorate of potash, 1 part,
> Powdered magnesium, 4 parts.

Both these mixtures are very rapid, give little smoke, and are quite safe.

The action is expressed by the formula

$$KClO_4 + 4Mg = MgO_4 + KCl$$

The perchlorate is preferable to the chlorate, being richer in oxygen. Duration of the flash, $\frac{1}{25}$ sec.

Another formula is—

Nitrate of zinc or nitrate of thorium, 1 part,
Powdered magnesium, 2 parts.

This gives an intensely bright flash. Duration, $\frac{1}{10}$ sec. to $\frac{1}{5}$ sec.

Powders containing saltpetre, sulphur, and antimony compounds are dangerous, and liable to explode even when being mixed. We would, therefore, strongly advise our readers to avoid them, as they are in no way superior to the simple and harmless chlorate of potash and magnesium mixtures.

In taking groups in a room it is well to place the dish on the top of a step-ladder, so as to give a more even illumination over the room. It also enables the light to be projected on to the group from a higher level. A large reflector just behind the dish is useful.

As regards the amount of powder necessary we have to take into consideration—

1. The distance of the person furthest away;
2. The ratio aperture of the lens used; and
3. The reflecting power of the ceiling and walls.

According to Herr Pettauer,[1] let G equal number of grains of the mixture necessary to give a correct exposure to an object at one yard from the lens working at F/8, which may be taken as two grains; D the distance in yards; R the ratio of exposure compared with F/8. Then

$$G = 2 \times D^2 \times R \quad . \quad . \quad . \quad . \quad . \quad [81]$$

Example.—A photograph of an assembly of persons is required. The furthest sitter is ten yards from the lens, above and at the side of the latter is the flashlight apparatus. The ratio aperture of the lens equals F/11. How many grains of the powder are necessary? Here $2 \times 100 \times 2 = 400$ grains. This will be found correct for the chlorate mixture. For the

[1] *B. J. Photo, Almanac*, 1908, p. 607.

perchlorate about half the above quantity, or 200 grains, with ceiling and walls of medium brightness.

For photographing caverns, mines, etc., in which instantaneous illumination is not required, two or three feet of magnesium ribbon in front of a reflector, or a few Bengal lights may be used, and lit in several places one after another, taking care that the light itself is screened off the lens.

§ 80. **On the Effect of Interposing a Parallel Plate of Glass with True Surfaces before and behind an Objective.**[1] — Two effects may be observed: a slight shifting and alteration in size of the image, and, secondly, a displacement of the focus backwards.

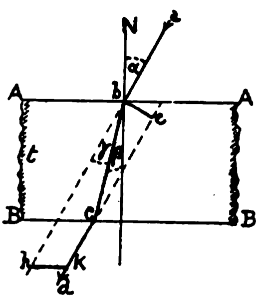


Fig. 155.

First, let us consider the lateral deviation. Let A and B be the surfaces of the plate, N the normal, *abcd* a ray passing obliquely through the plate and making with N the incident and refracted angles α and β respectively, t equal thickness of the plate.

Through b drop a perpendicular be to dc produced backwards, and $\alpha - \beta = \gamma$. Then $be = bc$, $\sin bce = bc$, $\sin(\alpha - \beta) = bc \sin \delta$.

Since
$$bc = \frac{t}{\cos\beta}$$

$$\therefore\ be = \frac{t \sin\delta}{\cos\beta} \quad . \quad . \quad . \quad . \quad [82]$$

the lateral deviation of the ray on emergence

$$\therefore\ \frac{t \sin\delta}{\cos\alpha \cos\beta} \quad . \quad . \quad . \quad . \quad . \quad . \quad [83]$$

is equal to the quantity measured by *hk* on the plate, which is the true lateral deviation of the image on the focussing-screen.

Hence the deviation is directly proportional to t and also to $\frac{\sin\delta}{\cos\alpha\cos\beta}$, which is governed by the inclination of the incident ray.

The result, therefore, of interposing a parallel plate *behind*

[1] See the author's paper in the April number of the *Photographic Journal*, 1908, from which the above is abstracted.

the lens will be to cause a lateral contraction of the image on the screen, the amount of which is independent of the plate. If the plate is at right angles to the optic axis, the lateral deviation will disappear when the focus is readjusted. In practice it will be found that the lateral deviation does not always quite disappear, the residuum of deviation left being due to the aberrations of oblique rays; but in a well-corrected lens they are hardly noticeable.

When the plate is in front of the lens the same thing happens, but *in an opposite sense*, *i.e.* the image undergoes a lateral deviation *outwards*, in other words, the image expands. But since the object is usually very much further away than the image, the angle which the rays from an object-point form with the lens is usually very small, and much less than the angle which the rays make with the lens when the plate is behind it, so that the amount of lateral deviation is extremely small. When the object is at infinity, *i.e.* at any great distance compared with the focal length of the lens, the rays form a parallel beam and the lateral deviation is *nil*. As the object is approached the deviation increases until, when the object and image are in the position of unit magnification (*i.e.* when both are at 2F), the amount of expansion when the plate is in front is exactly equal to the amount of contraction when the plate is behind the lens.

Secondly, *consider how the focus is altered by the intervention of the plate.*

1. *The plate is put in front of the lens* (Fig. 156).—If the object is very remote the displacement will be *nil*, since the rays from any point in the object will enter the plate and emerge as a parallel beam. As the object is approached the angle of divergence will go on increasing, and with it the displacement backwards of the image from the position of the conjugate focus F when the plate is removed. At the position of unit magnification this displacement will be at half the maximum. When the object is at the anterior focus the plate will produce the maximum recession of the image, but of course only theoretically, since then the image will have receded to infinity. The maximum distance being $t \cdot \frac{\mu - 1}{\mu}$, t being the thickness of the plate and μ its refractive index.

2. *The plate is put behind the lens* (Fig. 157).—In this case

the rays incident on the plate are always convergent, and for a very remote object the displacement of the focus backwards will always $= t\frac{\mu - 1}{\mu}$ whenever the plate may be situated between the lens and the screen. As the object is made to approach the lens the displacement diminishes in the same ratio until, at 2F, the maximum shifting is reduced to one-half or $t\frac{\mu - 1}{2\mu}$.

Since the colour screen which represents the plate is always in practice very thin, viz. from $2\frac{1}{2}$ to 3 mm., and the index of the glass is usually between 1,51 and 1,54, the amount of displacement does not much exceed 1 mm., an amount which

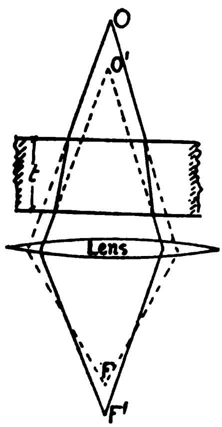


FIG. 156.

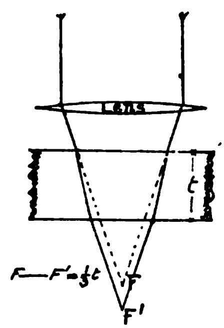


FIG. 157.

may be neglected, except in copying objects in one plane, such as pictures and maps, and in portraits and groups. If the glass is not worked, *i.e.* if the surfaces are not true planes, it will refract unequally, and aberrations of all kinds will be set up, which will more or less mar the sharpness of the image.

The practical outcome amounts to this—

When the plate or colour screen is in front of the lens no readjustment is required unless the object is within about three or four times the focal length of the lens, or for critical focussing, as is required for copying maps and pictures. When the colour screen is behind the lens a slight readjustment is necessary if a critical image is desired. For landscape photography no readjustment of focus is required, as a rule, in any case, since the

subject is spread over a great number of conjugate planes, so that if the horizon is thrown a little out of focus it will correspondingly benefit the middle distance.

As the thickness of a Lumière plate is usually from 17,5 mm. to 2 mm., placing the colour screen behind the lens will not entirely compensate for the reversal of the plate in the carrier, as it will only neutralize a little over a third of its thickness, but for practical purposes it will do so. The best plan is to reverse the *focussing-screen*, taking care to use one of about the same thickness as the Lumière plate. The alteration due to the colour screen may then be neglected for landscapes.

The colour screen may be roughly but quickly tested for trueness of surface by looking through the glass held as obliquely as possible to the eye at a line of print or an advertisement hoarding. If the glass be then moved both to and fro and laterally any imperfections in the figuring will be easily seen by the distortion of the type.

CHAPTER IV

SENSITOMETERS

§ 81. **Effect of Colour on Rapidity.**—In order to give the correct exposure it is not sufficient to know the intensity of the lens and speed of the shutter, the sensitivity of the plate for

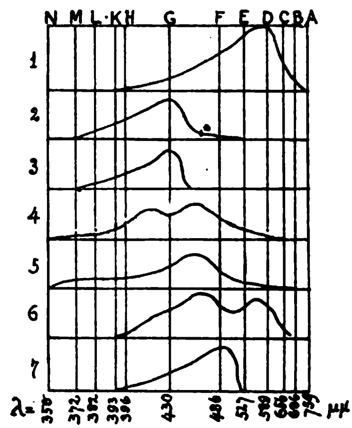


FIG. 158.

1. Luminosity curve as seen by the human eye.
2. Sensitivity of silver iodide and nitrate, direct blackening on paper.
3. Silver iodide gelatine plate (developed).
4. Silver bromide and silver iodide in gelatine.
5. Silver bromide gelatine plate.
6. Cadett's spectrum plate.
7. Bichromate in gelatine.

various parts of the spectrum must also be known. In the above diagram, taken from Englisch's "Photographisches Compendium," the sensitivity of various makes of plates for the actinic part of the spectrum is given (Fig. 158). The vertical

height of the curve (ordinate) gives the light sensitometer value. The horizontal line (abscissa) gives the range for different spectrum lines. It will be noticed that while the C, D, and E lines (*i.e.* round about the yellow) are the brightest part of the spectrum to the eye, the silver iodide and bromide salts, which form the sensitive ingredients in photographic plates, have very little action near the yellow, and most between F and G, *i.e.* blue and blue-violet part of the spectrum. The result being that in the print the long rays of orange and yellow come out too black, and the violet and blue parts much too light compared with what we see with our own eyes. Vogel, in 1877, made a discovery that by adding certain colouring matters (eosin and cyanin) to the emulsion, the curve could be made to rise over the yellow and orange parts of the spectrum. Abney went further, and made an emulsion sensitive to the red. This has been carried still further (beyond the B line) by the discovery of pinachrome and dicyanin. Still the sensitivity of the bromide of silver for blue remained abnormally strong, and Eder partly got rid of this by interposing a yellow screen in front of the lens, which absorbed the blue rays; but this screen, together with the excess of added red colour, greatly prolongs the exposure. It is obvious, therefore, that the rapidity of the plates varies immensely, and that for different coloured objects, differently treated plates must be selected. Such plates are termed isochromatic, or orthochromatic. After immersion in the dye, a prolonged washing for three hours, and thorough drying, is essential to preserve the keeping qualities of the plate, which will often extend to upwards of a year if that is done. In order to test the rapidity of plates for sunlight or certain parts of the spectrum a sensitometer is used, and to save the worker from having to find this out, it is usual to mark on the outside of the plate box the sensitometer number.

§ 82. **Special Forms of Sensitometers and Speed Measurers.**—Formerly the sensitivity of plates was calculated by means of Warnercke's Sensitometer. This consists of a glass negative ruled into twenty-five squares (Fig. 159), each one being slightly denser than the next lower number, the densities being reproduced by photography from a reversed positive. This negative was placed on the plate to be tested, and fixed in a printing-frame, or placed in contact with a phosphorescent plate excited by magnesium light for a given time, and the most opaque square, which just allowed the figure to be

deciphered, indicated the rapidity of the plate in degrees Warnercke, or W.

This method has been replaced in Germany by Scheiner's Sensitometer, which consists of a rotating disc perforated by twenty openings which follow one another in the ratio of 1,127. The apparatus is illuminated by a Hefner's standard light. The smallest opening through which the light leaves an impression after development gives the sensitivity in degrees Scheiner. This is liable to a reading error of from 1° to 2°. Rapid plates correspond to about 14 Scheiner, instantaneous ones to 15–16S. A sensitometer consisting of a rotating sector, furnished with a ring divided into steps, is now largely used in England, and was invented by Messrs. H. Hurter and Driffield. For the estimation of the time of exposure, Wynne's Infallible Meter and Watkins' Exposure Meter are extensively used in Great Britain. The more an objective is stopped down the longer must be the exposure. This, as we have shown elsewhere, varies inversely as the square of the aperture. The light intensity is measured by Wynne's instrument by the time that the strip of sensitive paper takes to darken to a shade given for comparison side by side on the supposition that the plate will be exposed for a time proportional to this, as recorded by the table attached to the instrument. Wynne's instrument is of no value for estimating the sensitivity of plates, but it is added to the table to show the relation between Scheiner and Warnercke. The column headed "Relative Sensitivity" enables one to calculate the necessary exposure of different kinds of plates when the exposure for one kind is known by Scheiner's table.

Exposure Meters.—From the preceding paragraphs it will be seen that three factors have to be taken into account in order to make a correct exposure for the plate. These are: (1) The ratio aperture of the lens; this has been fully dealt with. (2) The light; this is found by the strip of sensitized paper as just explained. (3) The speed value of the plate; this is generally found by the manufacturer of the plate, and is often recorded on the box in terms of Watkins', Wynne's, Hurter and Driffield's, or Warnercke's tables, which are to be found in the Appendix (Table 15).

We give an illustration of Watkins' speed measurer, which is exactly similar in principle to Wynne's.

It is used as follows:—Supposing a Lumière plate is being used, and the stop of the lens is F/16. The meter is held with

the dial facing the chief source of light and the back of the meter towards the object. If there are dark shadows in the foreground the meter should be held in the shadow, or if that is impossible for any reason, one must hold it in one's own shadow, letting the dial face the sky. A piece of fresh film is then rotated between the two grey sectors, and the time it takes to turn the same colour as the darker of the two sectors is noted. For example, the ortochrome plate factor is 2, you therefore set the figure 2 on the outer dial against F/16 by rotating the glass dial and back (held firmly together between the finger and thumb) until the number 16 is opposite the number 2. Now find the number corresponding to the number

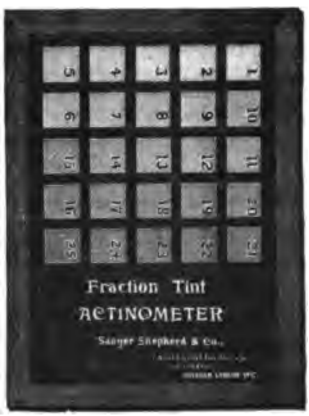



FIG. 159.

FIG. 160.—Watkins' Speed Measurer.[1]

of seconds required to darken the film on the opposite side of the dial, and the number opposite this on the outside scale will indicate the exposure in seconds. The lighter of the two sector shades is used for photographing interiors and badly lighted subjects. It takes a quarter the time for the film to darken to that shade, and thus shortens the time for exposing the film, which otherwise would take too long. For interiors and very dull lights you must consider the plate factor for ortochromes as 1.

[1] See Watkins' "Manual," an invaluable book for the photographer, price 1s. Another extremely practical (and, in fact, almost indispensable) guide to everything relating to exposure and development is Wellcome's "Photographic Exposure Record," a new edition of which is printed each year. It can be had from Burroughs, Wellcome & Watts, price 1s.

Example.—The Lumière plate number is 2, the F/No. is 22, and the film is found to darken in 16 seconds. Turn the inner disc until the figure 22 is opposite 2, and opposite 16 will be found 130, the number of seconds of exposure required.

§ 83. **Sir W. Abney's Method of Making a Colour Sensitometer.**—It is important in making a sensitometer that it should be used without artificial light, if possible, since the latter is very deficient in blue rays; secondly, that pigments should be used for colouring the test card; and lastly, that each of the pigments should have the same colour luminosity as one of the three components which go to make white. For example, if a red screen were being searched for, the red component in each pigment should be of the same value, so that the negative taken if the screen were correct should show the same density with each pigment.

The colour of any pigment can be decomposed into one, two, or three of the components which form white light. Now, as Abney points out, white light as it appears to the eye is made up of a certain percentage of luminosity of red, corresponding to the spectrum at the red lithium line; of blue, corresponding to the blue lithium line, and of green to the green magnesium line. These are the three shades of colour which cause sensations most closely agreeing with the Young-Helmholtz theory. A red pigment can be matched with a mixture of only two of these standard colours. A yellow pigment may require all three colours, and so on. It may be shown how all pigment colours (except purple) can be referred to one colour of the spectrum diluted with a certain percentage of white light. Since each colour of the spectrum can be expressed in terms of one or more of the three standard colours, it becomes easy to translate the colour of the pigment into a definite mixture of the three standard colours. "Let us take as an example the case of white and red, and suppose that the composition of white was 68 red + 30 of green + 2 blue = 100 white, and of the red, 90 red + 10 green = 100 red pigment, but that the luminosity of the red was only 10 per cent. of the white. Then in absolute luminosity there would be only 9 red + 1 green in the 10 red, which would $= \frac{1}{10}$ luminosity of the white, so that the white in red luminosity would have $\frac{68}{9} = 7{,}55$ times the luminosity of the red. To make the two equal, the white would have to be reduced in brightness to that amount. This can be done by having a

black disc with a red central area (see Fig. 161). A part of a ring of white which would occupy $\frac{1}{1{,}75}$ of the circle, after allowing for the amount of white which is reflected from the black surface, would show on the disc."[1]

When rotated round the centre, the same amount of red colour is seen in the red and in the white, and if one were satisfied with two colours, all that would be necessary to obtain a red screen would be to find some coloured transparent material through which an exposure would be made, which would give a negative, making the red and white of the same density. But two colours are not as a rule sufficient, so that other colours have to be placed on the disc. Having then

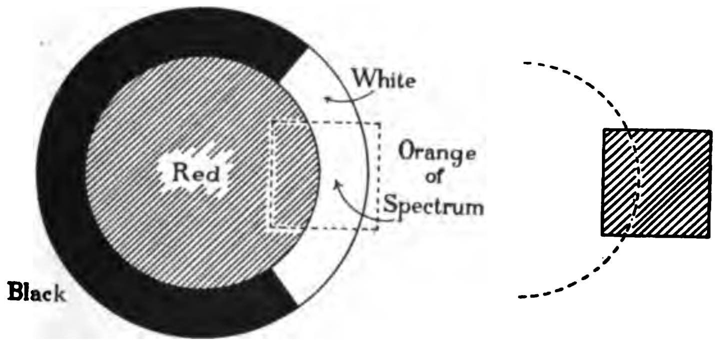


FIG. 161.—Sir W. Abney's Sensitometer (copied by permission of the author from his original paper).

found the proportions of red in these two colours, there is a simple way of finding the amount of black to be added to other colours. If the red and white discs just described be placed in a patch of spectrum light, it will be found that there is one place on the spectrum from which if light be taken and thrown in a patch on the rotating disc, the luminosity of the white disc will be uniform, though the colour falls on the red and on the white. This will be at a definite place in the orange, a little nearer the red than the sodium line.

Now, if any other pigment had been measured as before described, and the necessary amount of it be pasted as a part of a ring on a patch, the disc will again be uniformly illuminated with this same patch of coloured light.

[1] *Photographic Journal*, August, 1906, vol. xlvi. No. 8.

So that to obtain a series of different coloured rings all of the same red illuminosity, all that is necessary is to rotate the disc in this light, and add the different colours as part of different rings till they appear uniformly bright in this particular light. In this way the ring discs for the green, blue, and other screens can be found.

CHAPTER V

COLOUR PHOTOGRAPHY

§ 84. **Colour Vision.**—In order to understand the rationale of three-colour photography, it may be useful to some of my readers if I try to explain the nature of colour vision and colour blindness.

The light emanating, or reflected, from objects around us passes through the optical system of the eye and forms an image on the orange-red concave mirror, termed the choroid, at the back of that organ. From thence it is reflected on to the terminals of the rods and cones which together form a minute mosaic of sensitive points insulated from one another, and which lie almost in contact with the mirror, being only separated by a single layer of pigment-holding hexagonal cells. This light impression gives rise to three sensations which are quite distinct—a light sense, a form sense, and a colour sense. The first is the faculty of distinguishing illumination and its degrees of intensity. This is effected in the most simple case by the presence of pigment spots in the cuticle of an animal or plant, and forms the most rudimentary of all forms of eyes.

The form sense is a higher development of the sight faculty, and needs a transparent refracting body to form a real image, and nerve terminals to convey the collected impression to the animal's brain. This image may be quite independent of colour.

The colour sense constitutes a still further development of vision, which we will now discuss.

As I have already stated, white sunlight can be resolved, by means of a prism, into six distinct colours, viz. violet, blue, green, yellow, orange, and red. These are the only pure spectrum colours which our eyes can perceive, although we have reason to believe some animals can see other colours

beyond the range of this spectrum. Wollaston, as the result of numerous experiments, came to the conclusion that four of these, viz. violet, blue, green, and red were primary colours, because he showed that indigo could be formed by combining violet, blue, and a little green; yellow could be formed by combining green with some of the red; and orange by uniting red with a little of the green. Wunsch stated that by mixing violet and green you could produce blue. Influenced by Wunsch, Young and (later on) Helmholtz abandoned blue as a primary colour, and adopted violet, green, and red as the three primary colour sensations. Moreover, they stated that all the colours in nature could be formed by suitable admixtures of these colours, and white by the equal action of all three colours together on the eye. Black they showed was not a colour at all, but was caused by the absence of all colour sensation. Thus, if these three (or four) primary spectrum colours be projected on to a screen by *separate* lanterns and then superposed, the result is a white disc of light, the colours being *added together* (additive method). If, now, you put a red glass in front of the lantern, on the top of that a blue, and finally a green glass, the red glass will absorb the green and blue-violet, and only allow the red to pass through; the green will absorb the red and blue-violet, and the blue-violet glass will absorb all the colours except its own. Hence no light at all will reach the screen, and the result will be a black patch, the colours being *subtracted* (subtractive method). But three colours are not really necessary to produce black, since any two complementary colours will effect the same purpose, as can be seen from the above example. There are, however, good reasons, as Professor Burch has pointed out,[1] for believing that Wollaston's four-colour theory is nearer the truth than the usually accepted one. If you look steadily for a minute at the red part of the spectrum in a spectroscope illuminated by a very intense light, and in which the rest of the spectrum is cut off, and then look at the entire spectrum through another spectroscope moderately illuminated, you will see the violet-blue and green bands; but the green runs right into the yellow as far as the C line, where it suddenly ends. The yellow will be found to have entirely vanished—it is all green. Now rest your eyes for about ten minutes and repeat the

[1] See his Lecture delivered before the Optical Society, *Optician and Photo Trade Journal*, June 26 and July 3, 1908.

experiment with the green part of the spectrum, and you will notice that you can again see three colours, but they are changed to violet, blue, and red. The green has quite gone and the blue runs straight into the red. In the same way you can blind your eyes to blue, and the green and violet will be seen to run into each other. Again, you may blind your eyes to the violet. This is more difficult, as it requires a longer gaze and a very intense light. The blue will still be visible, but it ceases abruptly at the violet end. Lastly, if you blind your eyes to the yellow by excluding the rest of the spectrum (which is readily done, since the yellow is the most intense part), you will observe that both the red and green have gone and you will see nothing but the blue and violet (Burch, *loc. cit.*).

To sum up. A red-blind person sees violet, blue, and green. A green-blind sees red, blue, and violet; a violet-blue-blind sees a little blue, all the green, and a little red.

Unfortunately, it is impossible up to the present to imitate violet, or to find in it natural colours. According to Dr. Edridge Green,[1] the corn-flower and some varieties of lobelia most nearly approach to it, so that we have to content ourselves with a blue-violet dye, *i.e.* a mixture of violet and blue, which is the closest imitation of violet that we can procure. It is quite possible that some glass or dye will yet be found that will give us a pure violet, as well as a pure blue. The other colours are much easier to find. Thus, ruby glass and the purple of Cassius (oxystannate of gold) form fairly pure reds. Sulphur and bichromate of potash make good yellows, and ammoniacal sulphate of copper in a saturated solution, a nearly pure blue. But the reader must not go away with the idea that these four primary colours stop abruptly. They each run on far beyond the point at which they appear to stop in the spectrum. "In other words, the red and green sensations overlap, as do the blue and green and also the violet and blue, so that we must take the middle point of the combined overlapping as the natural boundary between the adjacent sensations" (Burch).

As to how we see colours we are quite in the dark. Most physiologists assign the perception of colour to the cones,

[1] "Colour Blindness," by Dr. Edridge-Green (Scientific Series. Kegan Paul & Co.). This is an admirable text-book embracing the whole subject, and full of valuable suggestions for colour photographers.

leaving to the rods the function of seeing feeble luminosities. Helmholtz' theory, that certain cones respond to the stimulus of red undulations, others to green, and others to blue-violet, will not bear close investigation. Some physiologists assign the sense of colour as well as perception of form to the action of the visual purple. This, again, is open to objection that there is no visual purple at the fovea, or in certain animals, *e.g.* bats, but this difficulty is got over by assuming that other bodies, such as visual white, visual green, or visual yellow, take on the same function. The author found all these bodies in the retinæ of animals. Thus, he has repeatedly demonstrated the presence of visual green and visual yellow in many of the carnivora (servals, pumas, jackals, foxes, seals). Again, we have reasons for believing that there is a colour centre in the brain as well. A remarkable case bearing on this point occurred in the author's practice. The patient was suffering from a form of creeping paralysis which gradually affected the limbs of the left side, and at the same time, as more and more of the muscles became paralyzed, the sense of colour slowly vanished in the corresponding eye, until ultimately the patient could see no colour at all, everything appearing black, grey, and white, like an engraving. This was tested by getting the patient, who was a good water-colour painter, to make a coloured drawing of the spectrum, first with the sound eye and then with the colour-blind one. Notwithstanding the absence of all sense of colour, vision was hardly affected at all, and the colour sense remained perfect in the right eye, while that of the left eye never returned.

Colour blindness, which affects about four out of every hundred people one meets, is due to a deficiency of colour sense in a portion of the spectrum, usually in that part which lies at the red end. Dr. Edridge-Green has classified colour-blind people according to whether they can perceive five colours, four, three, two, or only one colour. Thus, one who distinguishes all six colours, or a six-unit person, may be considered as normal. One who distinguishes five of the spectrum colours confuses orange-red and red, orange-yellow and yellow, purple-violet and violet, bluish-green and green. Whereas the two-unit person only sees two colours, and confuses red, orange, yellow, and green on the one hand, and blue and violet on the other.

The Young-Helmholtz theory fits in better than any other

with the phenomena relating to colour photography, but it by no means harmonizes with all the facts connected with colour vision. Thus, a two-unit red-blind person ought to see green best, whereas he sees yellow most distinctly. Again, the phenomena of after-images cannot be explained by this theory. Nor does it account for the additive and subtractive formation of white and black sensations in persons possessing only two or three units of colour perception. Furthermore, a pencil of light (white or coloured) focussed on a very minute area of the retina will produce the sensation of white, whereas it ought to give rise to a very decided colour.

Lastly, if it were true that the retina consisted entirely of three groups of fibres, corresponding to red, green, and blue-violet sensations, how can persons blind to all these colours have nearly normal vision?[1] and how can they see white objects as white?

We are entirely ignorant of the function of the substance secreted by the outermost layer of the retinal (hexagonal cell) layer, called by Boll the "visual purple." We know it is not essential to vision, but I have ventured to put forward the theory that it enables one to see better in a dim light, since it collects mainly round the outer ends of the rods, and not the cones, which alone are present at the fovea in man. My theory, which I think harmonizes best with the facts, is briefly as follows: We know that this visual purple is rapidly decomposed in the presence of bright daylight and at the same time is continually being re-formed. Now, in bright sunshine this visual purple is used up as fast as it is secreted, so that if one steps into a dark room, the purple having been nearly all used up, one cannot see anything, and one has to wait a minute or two until the purple accumulates, which it quickly does. As the amount increases the vision improves, or, to use a familiar expression, the eyes get accustomed to the dim light. If, now, one steps out of the room into the bright sunshine the amount of accumulated purple generates so much visual energy that one is dazzled and almost blinded for the moment until the superfluous store of purple is decomposed. It may be objected that bats, which can certainly see in a very dim light, have no visual purple at all, but then their rods are bathed in a visual substance which is at first a blue-violet-grey or buff, and then becomes

[1] For a complete statement of the argument, *vide* Edridge-Green, "Colour Blindness," chapter ix.

nearly colourless, like that secreted at the human fovea, and this possibly answers the same purpose.[1]

But the whole subject of colour vision is in a very nebulous state, and there still remains much to be discovered.

§ 85. **Lippmann's Colour Photography.**—If, instead of placing a very fine-grained orthochromatic dry plate in the slide with the sensitive film towards the lens, as is always done, we have a special slide made which can be filled with mercury, so that the sensitive film can lie flat against the metallic mercury mirror, it is possible to produce many of the colours of bright objects on the negative, and fix them in the usual way. This was done in 1890 by Professor Lippmann, and the explanation is as follows:—

Let us suppose (Fig. 162) a series of parallel (plane) waves

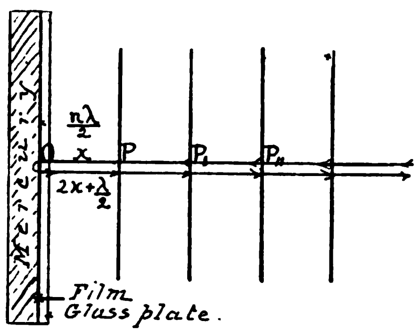


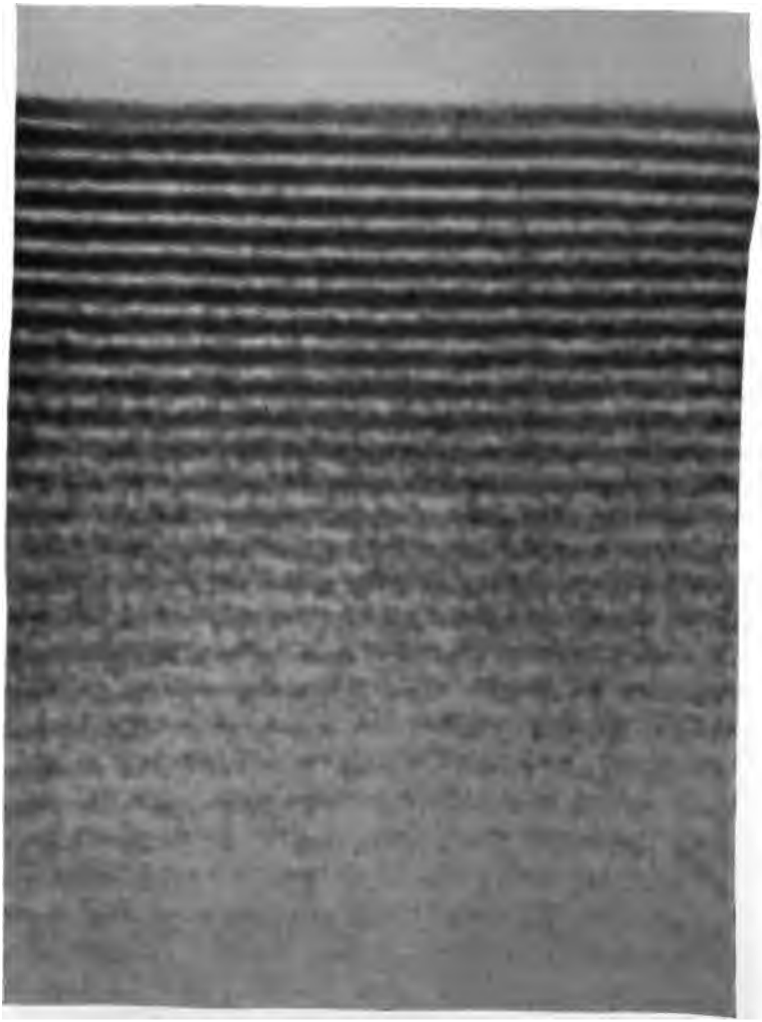
FIG. 162.

to be refracted through a lens on to such a plate in the camera. The waves will pass through the film and be reflected at the surface of the mirror.

These waves will, on their return, engender a number of stationary waves, owing to their neutralizing the opposing waves. Consider a point P in the film, which is at a distance x from the mirror. Then the waves about to proceed to O from P will encounter the waves which have been to and are returning from O, so that at P we have two sets of waves, the direct waves and the reflected waves. They both started in the same phase at P, but the reflected waves have travelled a distance equal to $2x$ further. Moreover, on reaching the

[1] This secretion must not be confused with the yellow pigment which lies in the outer molecular layer of the human macula. I have noticed this blue-violet-grey in many of the snakes' retinæ.

PLATE VII.



[Copyright.

FIG. 163.—Section of a Lippmann Photographic Film, made through the red end of the spectrum of arc light (× 11,000). Prepared and photographed by Edgar Senior, Esq., and reproduced here by his permission. Zeiss' Apoch. Obj. 3 mm. Oc. 2; yellow screen.

To face p. 216.]

mirror, they have gained half a wave length, because the reflection took place at the surface of the denser medium, since, by a well-known law, reflection at the surface of a denser medium causes a retardation $= \frac{\lambda}{2}$ in the wave.

Hence the path traversed by the returning wave $= 2x + \frac{\lambda}{2}$. Now this must be an odd number of half-wave lengths, provided that $PO = \frac{n\lambda}{2}$, n being an even number, since we have the extra $\frac{\lambda}{2}$ to make the total an odd one. If this is so, there will be interference throughout the planes P and P_1, because P_1 is separated by the distance x from P, and so for the other planes P_2, P_3, etc., throughout the film. The distance between these planes is equal to a given wave length of light for a definite line of the spectrum, so that these planes will vary for each colour, being closer together towards the violet end, and wider towards the red. Wherever the reflected wave meets an incident wave in the opposite phase, the trough of the wave will be filled up, so there will be a calm surface, and it will have no effect on the silver bromide at that spot, but where it meets its opponent in the same phase, the wave will be intensified and have a strong action on the silver bromide particles. If, therefore, the plate is developed and fixed, there will be a series of planes of darkened silver particles at regular intervals, the width being in strict proportion to the length of the wave, while in between these will be other planes corresponding to other parts of the spectrum. Dr. Neuhaus first succeeded in stripping off a piece of such a film, and making very thin sections, which, when highly magnified, showed an appearance similar to Fig. 163.

The dark lines are due to the reduced silver particles, the bright lines to planes where no action occurred. If, therefore, the film, when fixed and dried, be turned so that the eye sees the film at or near the angle of reflection, the colours corresponding to those of the original object photographed will be distinctly perceived. By fixing a wide-angle prism behind the plate so that the rays are totally reflected, the colours will be brought out much more vividly. In this way, not only can the solar spectrum be reproduced, but, under favourable circumstances, landscapes, flowers, butterflies, and other brightly coloured objects may be photographed. Many of the old

Daguerrotypes showed traces of the natural colours, as can be seen in specimens at the present day if observed at the proper angle, since the polished silver backing took the place of the mercury trough, but it remained for Lippmann to give the correct explanation of the phenomenon.

§ 86. **Joly's Method of Colour Photography.**—This is essentially a three-colour process, invented by Professor Joly of Dublin, in 1897, in which the three negatives are combined in one by placing the three colours side by side. The method is as follows:—

A glass plate is ruled with a series of orange, blue-green, and blue lines, about $\frac{1}{250}$ in. apart, and repeated in the above order across the plate. This triple-coloured glass is placed just in front of a sensitized plate, and a photograph of a coloured object is taken in the camera and developed. The negative may therefore be considered as composed of three parts, each corresponding to its particular line. A transparency is now made by contact, and another plate, ruled with the same number of lines, is placed in contact with it, only, instead of the coloured lines being orange, blue-green, and blue, they are now ruled red, green, and blue-violet, thus corresponding to the three-colour sensations. The red lines are adjusted to fall on the image formed behind the orange lines, the green on the blue-green, and the blue-violet on the image formed behind the blue image. It is of prime importance that the lines are in exact régister, otherwise the whole aspect of the picture will be changed. Therefore the lines on the negative which were behind the orange lines of the screen, must, when viewed through the positive transparency, be exactly in register with the red lines of the second screen, and so for the other two colours.

The positive and second screen can be placed in register, and thrown on to a sheet by an optical lantern, and a facsimile in colours of the original object may be seen by an audience on the sheet. It is necessary that the sheet should be at some distance from the audience, otherwise the lines, being highly magnified, would be seen. At a little distance away the lines blend, and a remarkably faithful and brilliant image is seen. If such a slide be placed in front of a window the colours can still be seen, but they vary according to whether the slide is looked at in front or from either side. Thus the colours of a dress may appear of a rose colour when observed obliquely from

the right-hand side, but a greenish-blue when seen from the left side of the picture. This is due to the fact that the positive and second screen have their corresponding lines in register when seen from the front, but when looked at obliquely, parallax is set up, so that on the one side the blue-green lines predominate, while on the other side the red are most seen. Since the red and green lines together produce yellow or orange, the green and blue-violet, blue, and the blue-violet and red, crimson, it will be seen that all shades of colour can be reproduced, although the mixing of lights and the mixing of pigments will not produce the same results.

§ 87. **Three-Colour Photography.**—The two processes just described are of scientific value only, being only to a very limited degree suitable for exhibition purposes. Three-colour processes, on the contrary, are daily gaining in favour, many of the positives being of great beauty, and in the hands of Sanger-Shepherd, the Rotary Co., the Lumière Co., the Autotype Co., and others, have become a commercial success. Unlike the former methods, the films can be mounted, framed, and hung up on a wall, and the coloured pictures seen from any position. The method was invented, independently, by Ives of Philadelphia, and Ducos du Hauron of France, and is founded on the Young-Helmholtz theory of colour vision. Ives devised a camera (see § 89), which he calls a Kromskop (Fig. 168), having two reflecting mirrors, by which three negatives of the same object are obtained simultaneously, one taken behind an orange glass, one behind a green, and the third behind a blue-violet glass. If, now, three positives are made, the first being illuminated by a pure red, the second by a pure green, and the third by a pure blue-violet light, and superposed, the combined image will appear in its natural colour when projected on a screen, or viewed through a stereoscope. According to the Young-Helmholtz theory, since elaborated by Clerk Maxwell, every colour in nature can be obtained from one or more of the three primary colour sensations, red, green, or blue (blue-violet).[1] Thus red and green, when mixed, produce the sensation of yellow; green and blue, that of bluish-green or greenish-blue; red and blue, purple; while brown may be produced by the admixture of much red and a little green and

[1] I have pointed out elsewhere that we have some grounds for assuming that there are not three, but four, distinct colour sensations, viz. red, green, blue, and violet. This was the opinion of Wollaston.

blue. The different shades of these colours may be produced by varying the intensities of the mixtures. A mixture of all the colours, or a mixture of red, green, and blue, or of blue and yellow alone, in the right proportions will produce the sensation of white.

It is much more difficult in practice to make the picture a truthful counterpart of nature than the theory would indicate. The first difficulty is to obtain the colour filters of the correct hue and proportionate intensity. For this purpose a row of coloured glasses are used as a test object, viz. white, red, green,

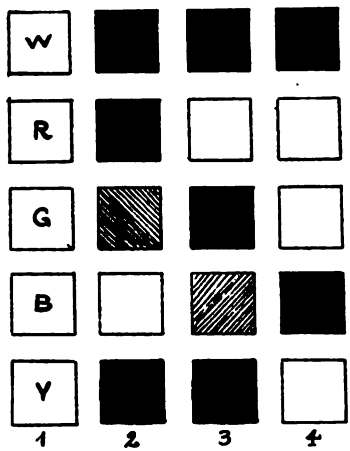


FIG. 164.—Method designed by Sanger-Shepherd to match colours by the additive process.

Column 1 shows the coloured glasses.
" 2 shows the negative images of the red, green, blue, and yellow glasses taken through a red filter.
" 3 same taken through a green filter.
" 4 taken through a blue filter.

blue, and yellow. Next, one has to find out and measure what proportions of the three primary colour sensations (red, green, and blue-violet) are necessary to exactly match the tint of each of the coloured glasses. In Fig. 164, on the left side we have a row of test colour squares of glass. To the right of these are represented three negatives taken behind these three filters respectively. No. 2 shows a negative when made through the red filter, No. 3 through the green, and No. 4 through the blue-violet filter. The top squares show a dense

silver deposit in all three negatives. The negative taken with the red filter shows a dense deposit in the space occupied by the red glass, a slight deposit in the green space, none at all in the blue-violet, but a dense deposit in the yellow space. In the same way the effects of the other two negatives are shown.

When the light filters have been accurately chosen, a plate is exposed behind each filter in a camera. It might be thought possible to take all three pictures at once by using a wide camera with three lenses, but this is impossible, because unless the three negatives are taken from exactly the same spot, the copies cannot be accurately superposed, since the difference in the point of view would give stereoscopic images which cannot be made to coincide. Each plate must receive such an exposure *that a white object may be represented by a deposit identical in position and area in each of the three negatives.* This forms the key to successful printing. If we project transparencies from these negatives on to a screen by means of three lanterns, we must place in front of each lantern slide a coloured glass similar to that used for the corresponding negative, *i.e.* we must illuminate the transparency from the red filter negative with red light, the green with green light, and the blue with blue light, but when we superpose the transparent prints, made from each of the negatives, we must first colour each of these prints not in the colours used for their respective filters, but in the complementary colours to these, *i.e.* in colours which transmit the other two colours which, added to the filter, make up white light. Thus the negative taken through the red filter is printed in a colour transmitting green and blue, these being the other two colours which, with red, form white light. This colour is cyan-blue, the complementary colour to red. It is, moreover, a light greenish-blue, quite different from spectrum deep blue. The green filter negative is printed in the complementary colour to green, viz. a magenta-pink, and the blue filter negative is printed in the complementary colour to blue, viz. canary saffron yellow.

The reason is as follows:—In the former case discs of red, green, and blue lights are overlapped, so that coloured lights are added to coloured lights (additive method), but in superposing one print over another we are adding not lights to lights, but opacities to opacities, since each additional print abstracts part of the light transmitted by the first one. Thus, if one prints a patch of red light on a piece of white paper the latter

reflects light of all colours and consequently appears white, but the patch of red absorbs the green and blue and only reflects the red, and therefore the patch appears darker than the white. If we now paint a patch of green and another of blue over the red patch, the latter will appear black and not white, whereas if light is transmitted through transparent discs of three primary colours in their correct proportions and superposed on a screen the result will be a white disc. Fig. 165 represents the additive effect of overlapping the coloured discs of red, green, and blue lights, the result being a white, or nearly white, patch on the screen, whereas Fig. 166 represents the subtractive effect of superimposing discs of gelatine films or glass stained with the complementary colours to red, green, and blue, the result being a black patch. The coloured illustration (Plate VIII.) shows

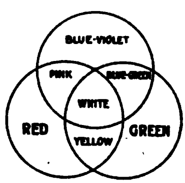


FIG. 165.—Diagram showing the effects of additive lights.

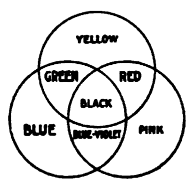


FIG. 166.—Diagram showing the effects of subtractive colours.

the effect of the superposition of the colours, to which the above figures furnish the key.[1]

In order to make a three-colour transparency, we must therefore proceed as follows :—A red filter negative is taken and a contact transparency made by exposing a plate behind the negative, and developed in the usual way, the grey-black image of reduced silver is now replaced by ferrocyanide of iron, the metallic silver deposit acting as a mordant, the result being a greenish-blue colour, which fortunately happens to be the exact complementary colour of the red filter. Two thin transparent celluloid films are now coated with a soluble gelatine film containing a trace of bromide of silver and sensitized with bichromate of potash like carbon tissue. This renders the parts affected by the light insoluble in water. One of these is now placed celluloid side down in contact with the green filter negative, and after the details of the image are quite visible the exposure is stopped. The film is then washed in

[1] On the cover of this book will be found the same results in another form, a triangle.

PLATE VIII.

Primary colours. Diagram, showing the effect of superposition of "Additive" *Lights*, as explained on p. 222.

Primary colours. Diagram, showing the effect of superposition of "Subtractive" *Colours*, as explained on p. 222.

[*To face p.* 222.

warm water to remove all the unaffected gelatine, and dipped in a crimson-pink dye bath, so as to get a pink print, the complementary of the green filter. Lastly, we obtain a print off the blue filter negative with the remaining film celluloid side down, and, after treatment in the same way, it is stained a bright yellow, which is the complementary colour of the blue; when these two prints are dry they are mounted together in correct register. The pink print is cemented on to the greenish-blue transparency, and the yellow print on the top of all, the films being placed *face downwards*. This is necessary, since the greenish-blue print on the glass is a direct print made by placing the sensitive side in contact with the film side of the negative, whereas the two celluloid films are printed through the back by placing the celluloid side next to the film of the negative, and both are turned round on finally placing them together. This not only secures the prints being all turned the right way, but the two most important components, viz. the greenish-blue and pink are mounted in actual contact, while the third (yellow) print is only separated by the thickness of one film of celluloid, which does not affect the results. The three pictures are then mounted behind glass and used as a lantern slide, or framed and hung in a window.[1] If the proper values have been given to the colours, the final result, whether seen on the screen or examined by reflected light, is strikingly effective and realistic.

Sanger-Shepherd manufactures a very practical three-colour camera. Bermpohl of Berlin makes a good and cheap colour camera, designed by Professor Miethe. Horn, a camera manufacturer in Wiesbaden, also makes a useful one which can at the same time be used as an ordinary camera.[2]

§ 88. **Butler's Three-plate Camera.**—Mr. E. T. Butler has designed a useful camera on the principle of Ives' Kromskop which has been experimented upon by Dr. Mees. It will be found very useful for procuring the negatives for the Sanger-Shepherd method. The camera is of the box form and fitted with grooves to hold three double-backs, two above and one

[1] If the reader is anxious for more complete details on this subject we would refer him to Messrs. Sanger Shepherd & Co., and to the Lumière Co. A full description of the processes is given in "The Photography of Colour," by E. Sanger-Shepherd, Cantor Lectures, March 5, 12, 16, 26, 1900, Society of Arts. (W. Trouce, London.)

[2] Sir W. Abney has recently designed a very ingenious camera, which enables three separate plates to be exposed simultaneously (see *Journal R.P.S.*, October, 1908).

behind (Fig. 167). The first sensitive plate, F, has a red filter in contact with it, the second, G, a blue filter, both made of patent plate, but the third sensitive plate, H, has none at all. In order that the light after passing through the lens should reach the plates F and G two glass plate reflectors placed at 45° are required. Since both the front and back surfaces of a glass plate reflect light, it would give rise to double images, were it not in some way prevented. Ives got over the difficulty by employing thin wedge-shaped reflectors and covering their backs with coloured varnish. Butler has got over the double images by employing two reflectors set at an angle of 45° to the axis in the following ingenious way. The first reflector consists of bluish-green glass (the complementary to red) which

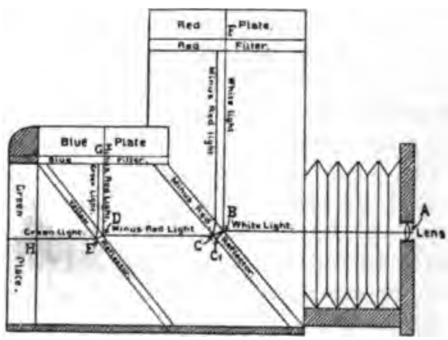


FIG. 167.—Diagram of path of light in Butler's Three-plate Camera.

absorbs the red light and transmits the blue-violet and green rays only. Thus the white light after passing through the lens reaches the first plate and is partly reflected directly upwards, and partly reflected and partly refracted from the back surface of the plate. On undergoing a second refraction into air the ray passes up parallel to the main pencil. On reaching the red sheet placed immediately in front of the sensitive plate, the green and blue rays are absorbed while the red rays pass through, thus all the light reflected from the back of the plate is absorbed and never reaches the sensitive film at all.

In the same way the second reflector consists of yellow glass the complementary to the blue, so that the rays reflected from the back of this plate are absorbed by the blue filter and only the blue rays reach the second sensitive film. Thus, again,

PLATE IX.

Colour photographs of an Orchid and a Chrysanthemum from Nature, by T. Ernest Waltham, F.R.H.S., reproduced from the Composite Transparencies, by the Three-colour process.

[*To face p.* 224.

the rays reflected from the back of the plate become absorbed and never reach the film. The remainder of the light, which is green (since it has lost its red and blue constituents), passes directly on to the third panchromatic plate, and, of course, requires no filter in front.

The order of the three coloured filters must be so arranged that each will get its proper share of the light. Hence the red plate which requires the longest exposure must have the greatest volume of light. It is therefore placed at F, so as to receive the full reflected beam of white light. The green filter is really in the brightest position, since it receives all the transmitted light, but since a red filter can be made which lets all the red through, but a green filter cannot be made to let all the green through, it has been found best to keep the green for the direct light, especially as all the plates are dyed with pinacyanol which makes them not very sensitive to green, although they are fairly rapid plates.

As it is necessary that the three images should be absolutely identical in size, the optical paths must be equal. In other words, the axial rays ABCDEH must be the same length as ABF or ABCDG. To do this the excess of length of the refracted rays BC and DE over the thickness of their respective plates must be added for the blue plate and the excess of BC over BC_1 for the red plate.

If we take the refractive index of each plate = 1,52, a little calculation will show that if the axial ray AB makes an angle of 45° with the normal, the refracted ray BC will make an angle of $\frac{\sin 45^\circ}{\mu} = 27^\circ\ 43'$, so that, taking the thickness of the plate BC_1 to equal 1, BC will be $= \frac{1}{\cos 27^\circ\ 43'} = \frac{1}{0,8887}$ or 1,125. We must therefore add $(BC_1 \times 1{,}125) - BC_1$ to the distance of the red and blue plates from the lens in the manner indicated.

In order to adjust the ratio of the three colours correctly, Mees puts pieces of film between the glasses, and photographs a black and white diagram, altering the depth of the film until the exposures are equal on the three filters. The films are then cemented in the glass and the positions of the filters adjusted until all three images are simultaneously in sharp focus. The difficulty is so to adjust the intensities of the screen and filters that the three negatives shall have the right densities with

the same amount of exposure. In other words, that each negative shall receive its proper proportion of light, so that the latter, after passing through the three filters, when combined, shall constitute white light. Of course, with this camera the exposure is the same for all three negatives and cannot be varied as is the case with other cameras.

The negatives which receive reflected light, viz. the red and blue ones, will be reversed, whereas the green negative which receives direct rays will not be so. This may be rectified by turning the green negative film-side out, taking care to allow for the thickness of the glass support. Mees uses a Ross' portrait lens, but an apochromatic or semi-apochromatic lens would undoubtedly produce more perfect images.

§ 89. **Ives' Kromskop.**—The accompanying figure shows the essential parts of Ives' Kromskop. A, B, and C are sheets

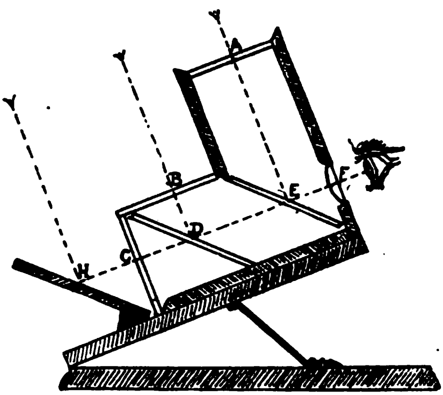


FIG. 168.—Ives' Kromskop, showing how the pictures are combined.

of red, blue, and green glasses respectively, on which the three pairs of positives made for these colours are placed. H, D, and E are plain mirrors inclined at 45°. F is one of a pair of stereoscopic lenses, *i.e.* of two convex prism lenses, the prisms having their bases directed outwards, and the lenses are each of slightly longer focus than the distance CF.

The mirrors and glass plates are so arranged with respect to F that the distances AE EF, BD DF, and CF are all equal, so that the images of each colour enlarged by the lenses FF will exactly coincide, and give rise to a single coloured aerial image

PLATE X.

Opal in matrix; Three-colour photograph, from the original at the Natural History Museum, South Kensington.

[*To face p.* 226.

in stereoscopic relief at the near point of the observer. This coloured image appears to stand out in the most vivid relief, and if the three positives are equally illuminated by an even light, by means of a fine ground glass placed in contact with the outer side of the three pairs of positives, and the colours correctly chosen, the result is exceedingly beautiful. Occasionally the colours appear bleached out in the lighter shades and the shadows appear too dull. By using a triple lantern three coloured images may be superposed on a screen, and although true stereoscopic pictures in relief cannot thus be obtained, since one cannot combine stereoscopic images on a screen as is done in the Kromskop, an apparent plastic relief not observed in black and white slides is obtained. I have heard this remarked by many people. The effect is even more pronounced when the picture is observed with one eye only. Possibly the explanation lies in the fact that the colour increases the sense of reality in the picture and enables the mind to supply the plasticity which experience tells us must exist in the actual object. This is only carrying a step further the well-known fact that if we look with one eye through a short tube at an engraving or painting, it will convey a sense of plasticity which is wanting when the same picture is regarded by both eyes.

§ 90. **Two-Colour Processes.**—The difficulties attendant on three-colour photography, and especially on making all three exposures at one time, has led to attempts being made with two colours. Gurtner has invented and patented a very simple process which, while ignoring the red element, still enables one to produce charming pictures of natural scenery. He first takes a chlorobromide emulsion plate, very thinly coated (in other words, a lantern plate), stains in the dark in a bath of naphthol orange, or aurantia dissolved in water, dries it, and then places it in contact with a panchromatic plate, film to film. The two plates are then placed in the dark slide, taking care that the glass side of the lantern plate faces the lens. The ground glass is reversed, as is done when taking an autochrome picture, to compensate for the thickness of the glass; and an exposure made in the ordinary way. The orange lantern plate absorbs the blue rays which act on the plate and form the image, and allows the red, yellow, and green rays to pass through the semi-transparent film. These act on the panchromatic film and form a second image by the action of the red, orange-green rays. The orange plate, which has a dark image

when the blue rays have acted, serves to print the yellow image, while the panchromatic plate, which gives a dark image under the red-green rays, serves as the negative for the blue image. A little trouble is necessary to adjust the density of the orange stain so as to give the relatively correct exposures for the two plates. In fixing, the yellow stain dissolves out. A print is then obtained, from the panchromatic plate, either by making a positive and staining it blue, or by making a blue print on an iron-cyanide paper[1] direct. A positive is made from the lantern plate (which has now lost its colour), either on a second lantern plate, or on a detachable celloidin paper. These copies are best fixed in ammonia, without being toned, becoming lemon or orange yellow. The two blue and yellow glass positives are now dried and placed in position, face to face; and a lantern slide formed by binding adhesive paper. If a paper print is required, the celloidin print is squeezed down on to the blue paper print after careful adjustment.

The results of this process are often very satisfactory and it has the advantage of simplicity, since any ordinary camera will suffice, no filters or dyes are needed, as is the case with three-colour processes, and only two prints need putting into register.

§ 91. **Single-plate Colour (Additive) Processes.**—Of these there are several processes invented, but they resemble one another in their fundamental principles. They are all based on the theory that white light may be considered as being made up of three primary colours—red, green, and blue-violet—and, further, that the filter screen being built up of these colours, each particle will permit light of its own colour to pass through, while the other two colours are more or less completely absorbed. Suppose a transparent screen acting like a filter is made up of successive rows of alternating red, green, and blue lines, dots, or squares in such a way that the entire surface is covered or ruled with successive rows of these colours, it is clear that light reflected from any multi-coloured object or landscape will, on passing through such a screen, be selectively absorbed. And the same will happen if a glass plate be covered over with tiny squares or grains dyed with these three colours. Thus the rays from red objects will pass freely through the red lines, squares, or grains, but will be more or less completely

[1] This paper can be obtained in packets from any dealer. It is very useful to judge the effect of a negative, as the prints are fixed in ordinary water, and are made in a minute.

arrested by the other two colours, while the rays from blue objects will pass through the blue lines or dots, and be absorbed by the other two. The intermediate shades and colours will be produced by a mixture of these three. In other words, the colours transmitted by separate screen units are combined in the eye provided the units are very small. Thus, supposing the red lets through 18 per cent. of the light, the violet 80 per cent., and the green 2 per cent., the result will be a purple. If red and green light act together equally they produce yellow. If you increase the red and green, and diminish the blue and violet, you will get a brown, and so on for all the other shades. Suppose the filtered light is allowed to act on a panchromatic plate (*i.e.* an emulsion rendered sensitive to the whole of the visible spectrum), and, after suitable exposure, developed. The result will be a negative having the colours reversed. The explanation of this is quite simple. Wherever the light has reached the sensitive film the silver bromide will have undergone a change, resulting after development in a deposit of blackened silver, the blackness (density) being proportional to the amount of light action at that spot. If the plate be held up to the light it will be noticed that no light will be seen over the areas where the light passed freely through the screen, but the areas which were not affected by the light will permit the colours corresponding to the lines or grains to pass through. Thus, if a red object had been photographed the light can only pass through the other two colours and will appear greenish-blue; on the other hand, if a yellow object be photographed, the red and some of the green rays will pass through. If the image be reversed by means of an oxidizing agent, the conditions will be the opposite. The red rays which were absorbed by the blackened silver will now pass through unobstructed, while the clear parts will become darkened. In this way a positive corresponding to the original hues will be produced.

As we have shown, the method of filtering each colour may be effected in various ways. In the Joly process, which was the prototype of the selective filters, the negative was made through a taking screen by closely ruled red, green, and blue lines. From this a positive was made and put in register with the viewing screen.

Another form of filter is the German line mosaic screen made of celluloid and coated with a panchromatic emulsion. From this direct positives are made by reversion.

§ 92. **Lumiere Autochrome Process.**—This beautiful and highly ingenious process depends on a colour screen built up of starch grains dyed with the three primary colours and overlaid with a thin panchromatic sensitized film. The grains are ordinary potato starch cells, each of which appear under the microscope as round cells having a central nucleus of $\frac{1}{150}$ to $\frac{1}{60}$ mm. (0,0066 to 0,017 mm.), the average diameter being 0,01 mm., *i.e.* the size of a white blood corpuscle. They are therefore just within the limit of perception if held up to the light and examined with a 10 times enlarging lens. Now, the diameter of a retinal cone averages 0,004 mm., or $2\frac{1}{2}$ cones to a starch cell; the distance of normal near vision is 250 mm. (10 in.), or 257 mm. in front of the nodal point. The size of the retinal image of a starch grain held at that distance will therefore be

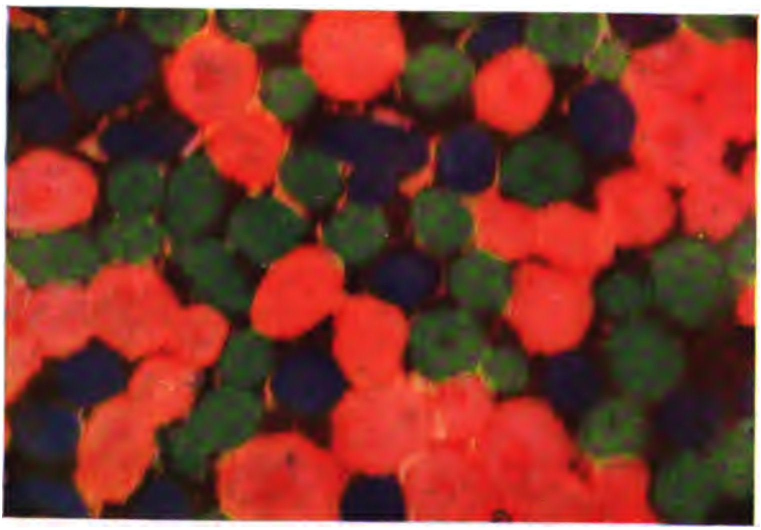
$$\frac{0{,}01 \times 15}{257} = 0{,}0006 \text{ mm. and } \frac{0{,}004}{0{,}0006} = 6{,}67.$$

Therefore the image of six grains will just occupy the diameter of one cone, and as the areas of circles are proportional to the squares of their diameters, *i.e.* $1 : 6{,}6 :: 1^2 : (6{,}67)^2$, a cone area therefore will contain the images of forty-six starch grains at the distance of the near point of vision. It might be argued on theoretical grounds that rice cells would afford a much more delicate medium than potato starch cells, as they are about one-tenth the size of the latter, and would afford ample scope for a more extensive distribution of colours, but it is found that the distance between these cells and the film is so large compared with their size that they would induce a destructive parallax and thus negative their selective action.

As this method is one of the few largely practised by amateurs, it merits examination in detail.

The glass plate is coated by the manufacturers with a tacky film, and then entirely covered with a single uniform layer of potato starch cells, which have been dyed respectively red, green, and blue-violet. These are first intimately mixed, so as to leave as few as possible of one kind together. This layer is then flattened by rollers, dusted with a black powder to fill up the interstices, varnished, and finally dried and coated in the dark with a panchromatic gelatine bromide emulsion. If one of these plates is held up to the light it should resemble an ordinary dry plate, since the three primary colours combine to give the effect of white to the eye. As a matter of fact the film

PLATE XI.



Dyed-starch-grain Filter. Three-colour print, copied from a Lumière Autochrome plate, showing the dyed grains; magnified 700 diameters.

[To face p. 230.

consisting of cells (seen best when the gelatine film is stripped off) has a pale salmon pink colour when held up to the light, since the inevitable impurity of pigment colours renders a perfect white impossible. The plate is inserted in the dark slide with the glass surface facing the lens, in order that the light may pass through the coloured filter before reaching the film. The slide may be lined with black velvet, which is more opaque and less likely to scratch the film than the card usually supplied. In order to give the correct values to the three colours during exposure it is necessary to put a colour screen in front of or behind the objective, so as to retard the excessive action of the blue-violet end of the spectrum. If no screen at all is used the final image will appear throughout a violet-blue colour. Moreover, any yellow screen will not do; in fact, the attainment of the correct colour is one of the difficulties which Messrs. Lumière have had to surmount. The screen which they have finally adopted, after repeated trials, is obtained by a double film stained a delicate rose orange-yellow colour, and protected on each side by optically worked plain glass. They can be obtained through any dealer in several sizes. The presence of the screen filter *in front of the lens* will not affect the character of the image nor the plane of its focus in any way. If the colour screen is placed *behind the lens* the image plane is thrown back a distance equal to one-third the thickness of the screen. Since the plate is reversed in the plateholder, *i.e.* with the film side away from the lens, the lens must be racked in towards the plate by an amount about equal to the thickness of the glass. If the ground glass focussing-screen be reversed, the visual focus will correspond to the position of the screen, provided the focussing-screen and the plate have the same thickness. This reversing is advisable, as one is liable to forget to rack in the necessary $\frac{1}{16}$ in. If, however, the lens is stopped down to F/16 or less, or is of long focus, even this error will be imperceptible, unless one is making a copy of an object in a single plane. Placing the colour screen behind the lens will also partly compensate for the opposite error due to reversing the plate, so that in this case no change will be needed anywhere.

The right exposure is a matter of great difficulty, since the rapidity of the plates is found to vary much in different batches. This is the more to be deplored, as the success of the finished picture is very largely dependent on correct exposure. As a

rough guide, it may be said that you should *under-expose for subjects in bright sunlight and at midday, and considerably over-expose* (*two or two and a-half times the calculated time*) *for dull light or objects in the shade.* It is advisable to use either Wynne's or Watkins' Actinometer. The Lumière orange screen increases the exposure about five times. The starch grain colour backing increases the exposure about six times, while the film is about the same rapidity as a Wratten and Wainwright's ordinary plate, which is half that of an Ilford ordinary plate. According to my experience, the plates require an exposure from twenty-five to thirty times that required for a rapid Ilford or special rapid Imperial plate (of say 70 Wynne or 80 Hurter and Driffield) or sixteen times a Wratten Instantaneous, all being used without a colour screen at the same time and place. Messrs. Lumière reckon it as equal to 14 Wynne or 2 Watkins for outdoor exposure, or half those values for indoor subjects and portraiture. Another way is to reckon the same exposure with F/8 stop that the Watkins' meter paper takes to darken. Quite recently Mr. Watkins has brought out a Lumière plate dial, which can be substituted for the ordinary dial of his meter; this gives the exposure time for these plates.[1] By changing the dial it is converted at once into an ordinary exposure meter. The instrument, including the extra dials, can be had for a few shillings. In photographing landscapes, I either give more exposure to the sky than the foreground, or I double the exposure and halve the development time. The reason is that in an ordinary negative the sky should receive much *less* exposure than the foreground, but in the autochrome a positive is made. This requires the opposite treatment, *i.e.* the sky must be fully exposed and developments shortened. In this way I have obtained a blue sky and white fleecy clouds with a fully exposed foreground and middle distance. Mr. Hinton tells me that he has got excellent blue skies by lifting the plate out of the developer and then pouring water over the sky area of the plate and immediately returning it to the developer, and, if necessary, repeating this three or four times.

After exposure the plate is developed with a pyro-bromide

[1] It may be interesting to some of our readers to know that focal-plane shutter exposures ($\frac{1}{10}$ sec. to $\frac{1}{12}$ sec.) may be successfully made during June, July, and August in bright sunshine between the hours of 10 and 2.30 on distant landscapes, river scenes, sea views, and snow scenes with F/4 or F/4,5 apertures, and on the two latter with F/5,6. But the scene must be brilliantly illuminated.

and ammonia solution, or by amidol, for from two to five minutes, according to the colours of the image. The dark-room light need not be extinguished, as Lumière advises, but it must be well screened by one orange and two red glasses, or, better still, by means of Wratten and Wainwright's special green screen. This is made by backing a specially selected shade of greenish-blue glass by a piece of yellow twill. Lumière and all photographic dealers now supply yellow and greenish-blue papers, termed "Virida" papers. He recommends for a 16-power lamp, three yellow and two green papers, to be placed in front of the lamp face, but two of each are usually safe. In both instances the yellow screen should face the light.[1] The light should be sufficiently intense to readily tell the time by a watch when held close to the screen, and the bottles and dishes and measures should be so arranged beforehand that the operator knows exactly where to lay his hands on them. The time is best estimated by illuminating one's watch, placed against the screen, and it is well to pour on the developer the instant before the second-hand reaches the zero mark. Stanley has invented a dark-room clock which works well. Watkins also supplies one. The author has also invented one which automatically multiplies the factor number by the time the image takes to appear, and rings a bell when the time is up.[2]

Personally, I judge the time of development by the appearance of the image alone. I commence development with the full amount of pyro recommended, but only half the full quantity of ammonia. Then, if the image is seen to flash out under twenty-five seconds, I add immediately an equal quantity of water to that of the developer used and a few drops of bromide. I then develop for three or four minutes, or until the image appears in full detail. This one can partly see while it is in the dish, but by the time the development is half completed, one may hold it close to the screen for a moment with impunity. This method allows the image to have time to get dense without the details becoming dull and flat.

If more than thirty-five seconds elapse, I pour off the developer into a measure and add a few cubic centimetres of Lumière's diluted ammonia solution to half an ounce or so of

[1] Green screens are preferable to red, being, in the first place, safer; and secondly, green gives more light to the eye than red if the light is feeble.

[2] It may be seen at the Royal Photographic Society's Rooms, 66, Russell Square.

water, and again pour over the plate. The plate must then be developed from three to five minutes. By this means the high lights are prevented from becoming opaque before detail is obtained in the shadows.

The negative is then well washed for almost half a minute. This is best done by holding the negative in a fresh dish under the tap, and as soon as the latter is filled with water, pouring it off and repeating ten or twelve times.

If it were to be examined at this stage, the image would be clearly seen, but the colours would all be reversed. The reason for this is as follows:—Supposing the object to consist of red roses and green leaves. The red colour will have passed through the red grains and have caused a corresponding deposit of blackened silver, which will become visible during development. On holding the negative up to the light, this deposit would obstruct the light so that the red rays would be cut off, but the green and blue-violet grains would let the light through, so that the rose would now appear as a mixture of green and blue-violet. If, now, the negative is converted into a positive, the conditions will be reversed. The red grains will now let the red through and the green and blue grains will obstruct the light over the rose area, so that the rose once more appears in its natural colour. Of course the same argument holds good for the other two colours. In order to get reversal, it is necessary to dissolve the negative image away by means of a solution of permanganate of potash, to which sulphuric acid is added. The negative is placed in a clean dish, and the solution is made to flow over the plate for about three minutes. The image will now be found to have undergone reversal, but it will be nearly white as well as lacking in brilliancy, and requires to be re-developed. The plate must be rinsed under the tap in the way just described and then exposed to bright daylight or powerful artificial light, such as a foot or two of magnesium ribbon. The subsequent operations may also be conducted in daylight, but I think gaslight is preferable. For the purpose of development, the makers advise a solution of dianol (diamidophenol) and sulphite of soda. All traces of this developer are now removed by a fresh bath of diluted permanganate solution, made by adding a few drops of the former permanganate solution to a dish full of water until the water is just perceptibly pink, and the image re-intensified, *if necessary*, by a weak acid pyrogallic and nitrate of silver

bath. The image is then cleared by a third bath of neutral permanganate, and finally fixed in slightly acid hyposulphite of soda for three minutes, and washed. If, after fixing, the image is not dense or brilliant enough to be satisfactory, it may be re-developed with solutions F and G,[1] or first reduced with ferrocyanide and then re-developed.

After the final washing, the plate may be rapidly dried by a centrifugal machine (if it amuses you), but it can be dried just as well by wiping all the moisture off the glass side, shaking it a few times to and fro in the air, and then placing it upright on several thicknesses of blotting paper or filter paper. (This latter detail is important, to prevent the water spreading under the film.)

When dry, the film should be further protected by a glass plate, which is fixed by gumming round the edges a strip of black paper (called a binder), as is done in making lantern slides; or it may be first varnished. This is only necessary when the diapositive is intended to be used as a lantern slide, since the film is liable to crack with the heat. The varnish usually supplied is too thick and is apt to dry in ridges. This may be avoided by diluting with an equal quantity of benzine, or, as McIntosh suggests, by placing the positive on a whirling table and rotating it as the varnish is poured on.

I find, as the result of my experiments, that under-exposure or under-development in the first solution tends to give a dull image, in which the blue often predominates. This latter defect occurs if, by any chance, a trace of daylight gets access to the plate. On the other hand, over-exposure or over-development in the first solution results in a thin image, in which the details of the high-lights are eaten away and the sky appears of a pinkish tint, due probably to the predominance of colour in the red grains.

Four precautions are especially important to ensure success after the picture is secured.

1. Beware of exposing the plate for more than an instant to *direct* red or green light during the early stages of development, as the plates are extremely liable to fog under conditions which would not harm ordinary plates. Therefore use very oblique light.

2. Be sure that the developing and re-developing powders and the permanganate crystals are completely dissolved, and that the solutions are quite free from undissolved matter, as a particle of either reducing or oxidizing substance will almost

[1] Distilled water only must be used for these solutions; the others may be made up in tap-water. The permanganate bath is of doubtful value.

certainly cause a stain if left on the film for more than a second, and such spots are impossible to be entirely got rid of. The worst stains are the green ones. These are due to minute cracks or holes in the film, which allow the water to soak in and dissolve out the green stain of the starch grains. Such stains often ruin the picture.

3. Do not leave the plate undisturbed in the developer, but rock the dish all the time to ensure an even action. This may be done with all the baths with advantage.

4. Wash well under the tap, but with a gentle stream to prevent injuring the film and causing green spots, and fill and pour the water out of the dish at least ten times in succession. This is especially necessary before applying D and F solutions.

The danger of frilling has been greatly overrated. I have never known it to occur in my own practice, but then I take care never to use water exceeding 60° F. If the reader is troubled by it he may either smear the edges with melted wax or paraffin, or use an Autotrans developing trough.[1]

The printed instructions and necessary chemicals can be bought already prepared in the right proportions in the form of tabloids (scaloids) from Johnson & Co., 23, Cross Street, Finsbury, or from Lumière Brothers. Hinton (Chemist), Bedford Street, Strand, sends out the chemicals ready made-up in ten six-ounce bottles, containing concentrated solutions (1 : 10) which save no end of trouble. They keep well for several weeks, and the set will develop about 50 quarter-plates.

The positive now resembles a coloured lantern slide, having the colours approximately those of the natural object. This, as with all three-colour processes, will only give approximations to the natural colours, for it is impossible with *pigments* of any kind to reproduce the infinite variety of tones and shades which are seen in nature. This can only be approximated by increasing the colours used, since the more numerous the colours the truer to the endless shades seen in nature will they be. This is why, in very high-class chromo-lithography, as many as twenty-five or even thirty different coloured inks are used in the printing. One of the charms of oil paintings lies in the opacity and depth of the body colour, which is singularly

[1] This trough is an open wooden box with a glass floor. The plate is placed in it filter upwards, and a rim lined with elastic rubber is placed in contact with the edges of the plate and screwed down on to it. Fallowfield supplies it at a very low price.

absent in printings made by any of the three-colour processes. Until these three objects are attained, viz. correctness of tone, range of hues, and depth of body colour, all processes will fall short of what can be attained by oil paintings, or even water-colour drawings. No process in photography requires more care, greater cleanliness, or greater exactness in the exposure and development than this one. The proverb, "Be sure your sins will find you out" is amply demonstrated by the autochrome method. When the exposure and development have been correctly performed the results are very fascinating, but, nevertheless, in the author's opinion, it falls short of Ives' exquisite process, which, when stereoscopically projected, presents an illusion which is the nearest approach to nature yet achieved by any method. The Lumière method has one great advantage over all others, viz. that of simplicity. Only one plate is required, and the negative is transformed into the finished picture. With proper exposure and thorough washing the processes can often be cut down to four with advantage, viz. (1) developing the image, (2) reversing, (3) re-development in daylight, and (4) fixing. As regards selection of subjects, fruit, flowers, pottery, portraits, and, in fact, all objects having bright colours seem to lend themselves very readily to this process. Landscapes with sky and cloud effects are often disappointing, since the sky being usually over-exposed it will have a dull or pinky hue. Von Hübl considers the autochrome process superior to the three-colour methods, owing to its perfect rendering of grey and black tones as well as the lighter colouring. Gold and silver are also perfectly rendered.

For full details of development see p. 293; and the following works can be recommended:—

"Die Theorie und Praxis der Farben Photographie mit Autocrome Platten," by A. von Hübl. Wilhelm Knapp, Halle. 1908.

"Instructions for the Use of Autochrome Plates." Lumière & Co., 89, Great Russell Street, London.

"Real Colour Photography," by R. Child Bayley. Iliffe & Sons, 20, Tudor Street, London. 1907.

"Colour Photography with the Lumière Autochrome Plates," by G. E. Brown and C. W. Piper. Houghtons, Ltd., 88, High Holborn, London. 1907.

"Autochrome Photography." Published by Jonathan Fallowfield. 1908.

"Real Orthochromatism." Published by Wratten & Wainwright, Croydon. 1907.

§ 93. **Warner-Powrie Process.**—This is the joint invention of Miss Warner and Mr. J. H. Powrie of Chicago, and it possesses certain distinct advantages over most of the processes we have described—

1. The cost of production is not prohibitive like the Joly method.

2. The lines are finer and closer together than in any of the others.

3. A positive in colours can be printed from the original colour negative by ordinary development and fixing. This is a great advance on the fifteen separate solutions needed in the Lumière method.

4. Coloured prints can be made from it.

The chief feature of the process lies in the screen. A grating of six hundred lines to the inch is placed in a printing frame furnished with adjustment screws. The sensitized bichromated plate is laid on it, covered up, and the screen side exposed to an arc light. The plate is then removed, developed, washed in warm water, and the insoluble image remaining in relief dyed with green colouring matter and mordanted (*i.e.* fixed) with tannic acid. The plate has now a third of its surface covered with green lines. The plate is recoated with bichromated gelatine, and again exposed under the grating, which is shifted off the coloured bands, the plate again washed in warm water, and the unacted third dissolved away. Red dye is now applied, and the process repeated to receive the remaining blue colour.

The result forms the Florence helichromic screen plate. This screen plate is covered with a panchromatic emulsion, and is then ready for use, and can be placed in the slide of the camera. Exposure to an object is made in the ordinary way through the lens. Of course the image could be easily reversed by the permanganate method, as is done in the Lumière process, but this should be avoided if possible. They therefore intend to manufacture two kinds of plates.[1] In those employed for producing negatives in colour, the lines will run lengthways; in those from which colour positives are to be printed, the lines will run across the shorter side of the plate. This will obviate all mistakes on the part of the operator. By employing filters

[1] These plates are not yet on the market (November, 1908).

which slightly overlap for the negative plates and abrupt absorption filters for the positive plate, the natural colours may readily be reproduced.

In order to make a set of three-colour positives, from which prints may be obtained by any three-colour process, they proceed as follows:—

The colour negative is placed in a printing frame, glass side to the light. Behind it is placed a thinner sheet of glass or

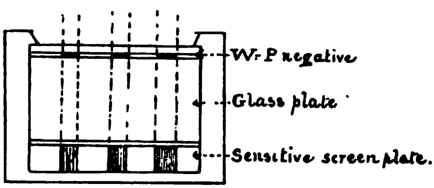


FIG. 170.

celluloid, so as to slightly separate the colour negative from the panchromatic sensitized plate beneath. The latter is now to be converted into a positive.

A separate monochromatic filter screen is now used for each of the three colours, and the light arranged at a sufficient distance to allow of parallel rays falling on the colour negative. The result will then resemble that shown in Fig. 170, in which

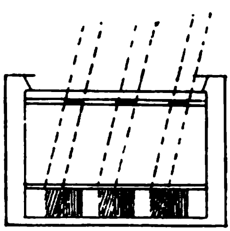


FIG. 171.

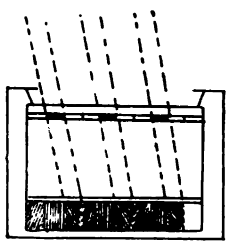


FIG. 172.

the colour negative, the intermediate clear glass, and the surface of the panchromatic plate are diagrammatically shown.

The light, it will be observed, can only affect a third of the plate, so that only one-third of the negative is copied in monochrome. The light is now shifted to one side (Fig. 171). This will affect the second third of the plate, and give rise to the second colour sensation. Lastly, the light is shifted to the opposite side (Fig. 172). This completes the process. Or

three sources of light may be employed at once, and the whole plate exposed in one operation.

In this way the red, green, and blue sensations in the plate can be obtained, from which (or from negatives made from them) the three-coloured print in pinatype, carbon, or other process may be produced.

If a colour positive be made by printing from the linear colour negative, exactly the same process is followed, except that no filter is used before the light, and the panchromatic plate is replaced by the positive screen plate which is laid, glass side down, upon the film of the colour negative. An exposure is made, as before, in one or three stages at different angles. The ruling of the negative screen will be found to be completely removed, just as it is during the printing of a continuous tone positive.[1]

There are several other processes in various stages of advancement, of which Krayn's is perhaps the best known, but they differ chiefly in the way in which the screen is built up. None of them are as yet on the market.

Uto Paper.—A peculiar jet black bleach-out paper has been recently invented by Dr. J. H. Smith, a gentleman residing in Zurich. This paper may be placed behind a linear screen plate, just as in printing a continuous tone positive, *i.e.* the effect of the light passing through any particular band is triplicated, either by the use of mirrors at each side of the printing frame, or by arranging the light at opposite angles, as stated above. At present the paper is not satisfactory, since it needs a very long exposure to bright sunlight, a fact which renders the process more suited to Egypt than to this country, and secondly, the colours do not bleach out uniformly. Smith's process is, therefore, still in the experimental stage, and doubtless, ere long, it will be replaced by a more satisfactory paper.

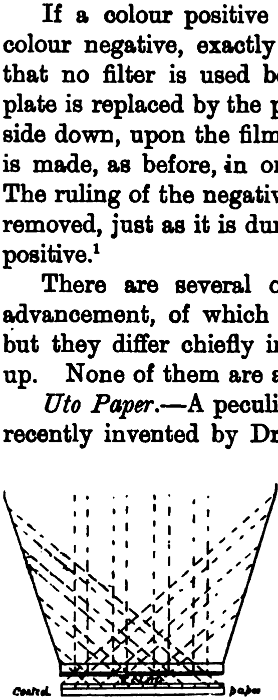
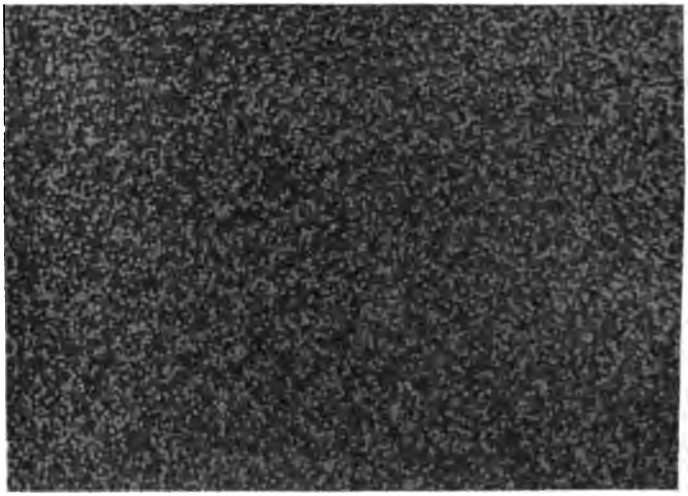


FIG. 178.—Diagram showing the method of printing on Uto paper through a Warner-Powrie Screen.

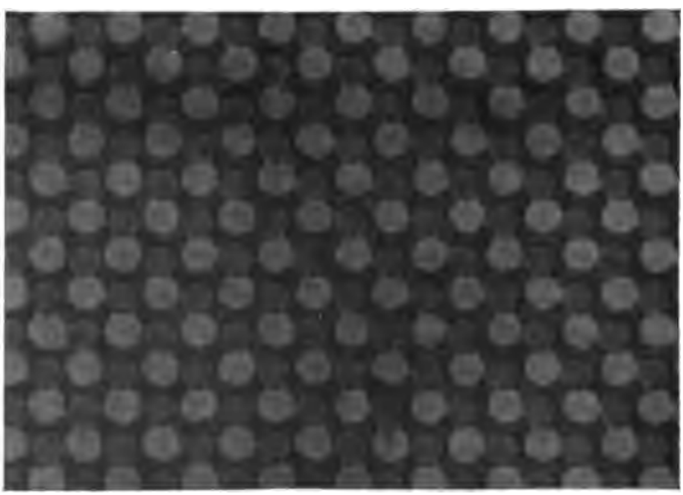
§ 94. **Finlay's Thames Plate.**—This plate is somewhat

[1] See a very complete description of this process in the *Journal* of the Royal Photographic Society, for January, 1908, by John H. Powrie, from which this description is largely drawn.

PLATE XII.



Autochrome-dyed Starch Grain Filter. From a photograph by the author on a Wratten panchromatic plate and yellow screen. Pillischer's 1¼ in. Obj.; 2. Oc. (× 42 diameters). Light grains red, grey grains green, black grains blue-violet.



Thames Three-coloured Disc Filter. From a photograph by the author on a Wratten panchromatic plate and yellow screen. Pillischer's 1¼ in. Obj.; 2 Oc. (× 42 diameters). Light discs red, grey discs green, black patches blue-violet.

To face p. 240.]

similar to the Florence plate, but instead of being covered with coloured lines, it is impressed with rows of alternating red and green circular dots. The interstices are filled in with a violet-blue dye, so that the entire plate is covered with the three colours, and presents no blank spaces.

This forms the colour filter in front of the sensitive film. Since the colours are much more transparent than the starch cells, the rapidity of the plate is correspondingly increased. The rapidity is said to be from four to five times that of an autochrome plate (it corresponds to 5 Hurter and Driffield), so that under favourable circumstances, and in bright sunshine, it is possible to use a focal-plane shutter with a lens of large working aperture and thus secure a coloured negative of objects in motion, which has hitherto been impossible.

The Thames film is much thicker and tougher than the autochrome, and will consequently stand rougher handling.

The average relative sizes of the coloured dots or lines in the three plates just mentioned are—

		Proportional size.
Autochrome starch grains . .	$\frac{1}{2500}$ inch . .	1
Florence lines, diameter . . .	$\frac{1}{800}$,, . .	3
Thames plate dots, diameter .	$\frac{1}{340}$,, . .	7

Since we reckoned (p. 230) that the image of forty-six starch grains held at ten inches distance just covered one cone area on the retina, it is obvious that one Thames disc will just occupy the same space. If, therefore, the discs were made any larger they would cause imperfect rendering of colours. In the author's opinion both the discs and the violet interspace might with advantage be reduced in size so as to allow of four colours, viz. red, green, blue, and violet, being represented, *i.e.* a red disc, a green disc, a blue disc, and a violet interspace. In this way he believes the colours would be more perfectly imitated, and have a greater range of tones, which even in the best autochrome pictures appear defective in red, green, and blue shades. Moreover, the red disc should be smaller and not larger than the green one.

The development of the plate is very similar to that of an autochrome, and is as follows :—

1. Develop with pyro-bromide ammonia as for an autochrome, but carry a little further.

2. Place for two minutes in a 10 per cent. solution of ammonium persulphate.

3. Then in acid permanganate of potash bath (for reversal).
4. Redevelop with amidol in bright daylight.
5. Fix (if necessary) for one minute in acid hyposulphite. Wash for five minutes—shake well to remove superfluous water and leave to dry.

Of course the plate must be well washed after each bath, as is done in the case of the autochrome plate. For further details of exposure and development, see p. 292.

The spoilt plates need not be thrown away since they will serve their purpose as a colour screen as often as desired by substituting any panchromatic plate for the spoilt film, which latter must first be removed.

The film is placed in contact with the coloured disc screen and the two, face to face, are placed in the slide and exposure made through a yellow filter as before. If after development the positive is satisfactory it should be dried and bound up permanently with the disc screen. If not satisfactory, the process may be repeated with a second plate, using the coloured disc screen as before. I believe the makers intend issuing the disc screen either coated or uncoated, with separate panchromatic plates to use with them.

§ 95. **Colour Prints.**—The colour processes hitherto described only furnish single diapositives, *i.e.* transparencies in which the picture is illuminated from behind, and seen by one person at a time, or projected on to a screen. But people naturally call for pictures which can be hung up on a wall, or placed in an album, and seen by reflected light. Such pictures also should be capable of reproduction. These two problems are by no means so easy of solution as would appear at first sight, although there are quite a number of ways by which they may be accomplished. Some of these methods yield at best only poor results, while others require an amount of experience and care which is possessed by very few persons. The following processes, however, are quite successful in the hands of careful workers.

Collotype Colour Process.—This consists of printing a bichromated gelatine plate under the colour negative, and then obtaining the print by inking up the resultant negative with a lithographer's printing roller, a method somewhat similar to the ordinary lithographic process. If a gelatine emulsion film treated with a solution of bichromate of potash is placed in the dark behind a negative, and then exposed to the light, it will

be found, on washing with warm water, that all the parts which have been acted on by the light will have become insoluble in exact proportion to the amount of light which has acted. Thus the shadows are formed by gelatine, and the high lights by nearly clear glass. In this way a negative in low relief is obtained. This relief resembles a prepared lithographic stone, and impressions on paper can be obtained from it by rolling over the relief a printer's roller, on which a lithographic ink of the desired colour has been placed, and then covering it with a piece of paper and passing it through the press. On removing the paper an exact copy of the picture will be found adherent to it. Since a print can be taken in this way with a lithographic ink of any colour, all that is required will be to make three collotype plates from the three negatives in the way we have stated; then to ink each of them over with one of the three colours which are the complementaries of the primary colours, and then to take a print on a single sheet of paper from all three plates successively, taking care that the three impressions lie in exact superposition.

In practice, four difficulties arise. First, the filter screens must be properly adjusted as regards their colours. This adjustment can be calculated out with precision if perfect inks were obtainable, but some compromise is at present necessary, owing to the impossibility of getting permanent printing inks of the correct hue and luminosity. Second, each of the three negatives must be correctly exposed, both as regards the subject and with regard to the other two negatives. Third, the depth of colour yielded by each negative to the paper must be correct. This is a great difficulty, as the amount of colour taken up by the paper is apt to vary in a most capricious manner, so that the final product of the three colours may not be true to nature. Fourth, the three impressions must be in perfect register.

Sanger-Shepherd's Imbibition Process.—This is a more practical method, fairly easy of application, and somewhat resembles his method for making transparency pictures. Three negatives are first taken through the colour screens, as already mentioned (§ 87). The positives from them are printed upon a special celluloid film coated with gelatine containing bromide of silver, sensitized by immersion in the sensitizing bath of potassium bichromate for three minutes and dried in the dark room.

The prints are made upon the film by printing through the celluloid—the celluloid side being placed in contact with the

film side of the negative and exposed to daylight until, on examination in weak light, all the details are visible on the film as a brownish-yellow print, very similar in appearance to an undeveloped platinotype print. The printed film is immersed in warm water, and in a few minutes the unaltered gelatine dissolves away, leaving a perfect white image full of detail attached to the celluloid base. The print is next fixed in ordinary clean hyposulphite of soda solution until the white bromide of silver dissolves, leaving a transparent, low relief in clear gelatine. After washing in water for ten minutes, the prints are ready for staining up. The print from the green filter negative is stained up in the pink bath, and the print from the blue-violet filter negative is stained up in the yellow bath—the staining being stopped as soon as the two prints, when held over the greenish-blue print, give neutral tints in the grey shadows of the picture. Should one of the positives be accidentally overstained it may easily be reduced by merely soaking in clean water. They are then successively squeegeed on to a piece of paper coated with a thin layer of gelatine. This absorbs the dye from the relief surface of the hardened gelatine. The gelatinized paper is then well soaked in water and spread over a glass plate, coated side uppermost. Then the pink-dyed positive (from the negative taken through the green screen) is squeegeed on to the gelatine paper until the whole of the colour has been taken up by it. In the same way the yellow-dyed positive (from the negative taken through the blue screen) is carefully adjusted in register on to the pink impression, and squeegeed down on to it. Lastly, the blue-dyed positive is squeegeed on to the pink and yellow image, which is kept wet to get an even impression. If any one of the colours is too weak, the printing plate for that colour may be re-dyed and used again. Thus a paper print is obtained on which an image built up of three colours is impressed. This may be squeegeed on to ground glass or polished glass, according as to whether a matt or glossy surface is desired. The print is now finished, and if the process has been correctly carried out, especially the correct exposures in the first instance, the result will be an extremely charming effect of colour. The skies are often very fine, indeed, much superior to autochromes, as the proper rendering of the sky is the chief defect in the starch-grain method. According to Sanger-Shepherd, the following are the chief sources of failure, with their remedies :—

The printing plates are liable to stick to the paper, because the paper has not been soaked long enough before use. It should be soaked in clean, cold water for at least ten minutes.

The printing plates take up the colour all over when immersed in the colour bath. This is owing to an over-printed relief; the relief must be thin. The best results are obtained by slow development in water at 100° F. to 105° F. It is because of the necessity for using a very low relief that a thin negative is recommended.

Dark, muddy prints.—This arises from printing plates being stained too deeply, or from the relief being over printed.

Blurred prints.—This fault is due to the paper being too wet, or because too long time has been taken in the transfer, owing to an unsuitable relief. With a correctly printed relief the whole of the ink should be transferred to the gelatinized paper within five minutes. The finished print should be at once pressed, surface dry, between clean blotters, and pinned up to dry in a current of air.

Full detailed instructions are sent out by Sanger-Shepherd & Co., along with all the materials necessary for carrying out their process.

Léon Didier's pinatype process.—This method has considerably grown in public favour of late, and is well able to hold its own among competitors. The process, unlike Sanger-Shepherd's, depends on the selective action of certain dyes on the gelatine. Thus, supposing the three gelatine bichromate printing plates have been prepared as in the last process, then the parts exposed to light will be hardened, the rest remaining soft. Now, it has been found that dyes may be classified thus—

1. Those (and they are the majority) which stain the whole surface, either uniformly or partly, by a selective action; the dye being in some cases removed by the water, in other cases remaining fixed.

2. Those dyes which stain the hardened parts of the gelatine more than the unhardened parts, since they enter into composition with the hard (light-impressed) parts which contain oxides of chromium.

3. A few dyes exist which do not touch the hard gelatine, but stain the (unacted on) soft gelatine. Such stains are called pinatype colours, and they constitute the dyes used in this process.

It will thus be seen that the pinatype method is the reverse of the Sanger-Shepherd, since the latter depends on dyes which adhere to the raised hard gelatine and come off on to the paper.

Pinatype colours should possess the following properties :—

1. They must be fairly soluble in cold water.

2. They must stain the soft gelatine strongly, and hardly touch the hard parts.

3. They must be fixed dyes, and incapable of being washed out.

4. They must readily stain the paper brought in contact.

5. The picture must retain its detail and sharpness after drying, and must not suffer from prolonged washing.

6. Lastly, the colours must not be liable to fade.

Fortunately all these properties can be found among the red, yellow, and blue dyes.

It may also be noticed that since these dyes do not stain the light-impressed gelatine, but only the parts unacted on, the pinatype print will be a facsimile of the original negative. In other words, the original negative taken through the colour-screen is reproduced by the printing plate exactly as in the Sanger-Shepherd process, but with this difference. By the latter method the print is made from the light-hardened gelatine which receives the ink, whereas by the pinatype process it is the unchanged gelatine which takes up and transfers the colour. In order, therefore, to make a positive print, our bichromated printing plate must be made from a transparency (diapositive), and not from a negative, as in the other method.

To sum up, the pinatype process consists of five stages—

1. *Making the negatives.*—Three negatives of the subject are taken through their respective screens.

2. *Copying the negatives.*—Three transparencies (diapositives) are made from the negatives on a fine grain emulsion, such as is used for lantern slides. These can be made to any size, so that if an enlargement or reduced print be wanted, the diapositives can be made to the size required in the print. The qualities of a lantern slide are transparency, brilliancy, and contrast, but the pinatype diapositives should be soft, without any great amount of density anywhere. This quality can be readily obtained by giving a full exposure, and using a diluted developer.

3. *Transferring the image to the printing plate.*—From the

diapositives three printing plates are made. These are glass plates thinly coated with gelatine and sensitized in a 2½ per cent. solution of bichromate of potash (15 grains to 2 oz. of water), dried in the dark (6 to 8 hours), and then successively exposed behind the diapositives. Each plate should be marked B, R, or Y in the corner, to indicate the colour to be used. The sensitizing solution must be kept cool (60° to 65° F.), and the time for each printing regulated by a photometer or actinometer (Warnercke's or Sanger-Shepherd's). It is about the same as for collodion P.O.P. The image appears faintly drawn on a yellow ground. The plates should be well washed until all the yellow has disappeared from the water. They are then dried, and are ready for use at any time.

4. *Dying the plates.*—Three baths are to be made. A blue bath of 10 tablets pinatype blue to 9 oz. of water for the plate from the red screen negative (immerse for 15 to 20 min.); a red bath of 10 tablets pinatype red to 1 drachm 0,880 ammonia, and 9 oz. of water for the plate from the green negative (immerse for 10 to 15 min.); and a yellow bath 10 tablets of pinatype yellow to 7 oz. hot water (immerse for half an hour).

5. *Printing the picture on paper.*—A sheet of transfer paper is soaked in water until it expands no longer. It is then gently and evenly squeegeed down on to the blue-dyed plate, which is taken wet from the bath. A piece of oiled paper is laid over the print to enable the roller squeegee to run smoothly. The progress of the transfer of the colour to the print must be watched by turning up one of the corners from time to time. On an average about ten to fifteen minutes will suffice. The blue print is then removed and transferred to the red dyed plate. In this case it is well to place a thin transparent sheet of celluloid between the two, and as soon as the two are in register, to hold the top of the print firmly and slip the celluloid from underneath, and then to squeegee as before. This precaution is necessary to prevent the transfer of colour before register is secured. In the case of the yellow dye this is not necessary, as it acts more slowly.

Lastly, the print now dyed with blue and red is squeegeed down upon the yellow-dyed plate. The order is therefore Blue-red-yellow, but you may make it Red-blue-yellow, or even Blue-yellow-red, but only experience will teach you which is best for each case. If any of the prints have been dyed too deeply, the colour may be thinned down by squeegeeing them on to a

piece of paper coated with gelatine until sufficient colour has been abstracted. In the same way an unfixed print which is too weak may be reinforced by squeegeeing it on to its printing plate. Retouching may be done on any of the wet prints with a brush soaked in the dye.

One great advantage of this process lies in the fact that the three impressions of colour are superposed on the single support, and not on separate gelatine layers which require to be accurately placed in register. The weakest part of the picture lies in the blues, which are apt to become too red owing to the varying effect of the green filter.

Many other beautiful and useful processes exist, such as the Rotary Co.'s Stripping Pigment Films, in which the printing is done through thin sheets of celluloid and each developed pigment image is in turn transferred to a piece of single transfer paper. The screen bichromate process, which has yielded such artistic prints in monochrome, is now adapted to three-colour printing. There are also the Hesekiel-Selle carbon process and the Perscheid screen process, but these methods, as well as the various three-colour mechanical processes, are quite beyond the scope of this work, and we would refer the reader to the works mentioned in the preface for the requisite information.

CHAPTER VI

FORMATION OF IMAGE ON THE PLATE

§ 96. **The Formation of the Latent Image and the Phenomena of Development.**—An immense number of substances are affected by the action of light, especially in the presence of air and moisture. Many of these changes are visible to the eye. Thus pigments and dyed materials are usually bleached; many organic substances (freshly planed wood, for example) are gradually darkened, while a large number of the chlorides, bromides, iodides, and nitrates of the metals are instantaneously affected if in solution, or finely divided, the change being largely determined by the presence of organic substances. This is one reason why albumen, gelatine, and collodion (gun-cotton) are used as layers or menstrua in which metallic salts are held in a state of fine division.

Of all metallic compounds the bromides, iodides, and chlorides of silver (or silver haloids, as they are called) take the first place as regards usefulness for photographic purposes. The modern dry plate consists of one or more of these salts intimately mixed with gelatine or collodion.

If such a plate be correctly exposed in a camera on a landscape, no change whatever can be seen on examination. If, however, any reducing agent, such as a solution of ferrous oxalate, or pyrogallic acid and soda, be poured over it in the dark room, an image will slowly appear, thus revealing the previous action of the light. If the plate be then washed and immersed in a solution of hyposulphite of soda, or potassium cyanide, the image becomes "fixed," and the plate may be exposed to the light without further visible change.

What has taken place to produce this image?

The moment the light falls on the silver bromide particles

in the film, a change takes place in their molecular arrangement. The bromine atoms are loosely combined with the silver atoms, and the light waves have sufficient energy to alter their position, so that some of the bromine atoms are loosened from their attachment. Thus, if we represent the silver atom by Ag and the bromine atom by Br, we may express the change as follows:

$$2AgBr = Ag_2Br + Br$$

Silver bromide = silver sub-bromide and bromine.

When the developer is poured over the plate the action becomes enormously increased, and the partial separation of the bromine atoms, which occurs wherever the light has acted, becomes complete. Our equation therefore becomes changed to

$$Ag_2Br = 2Ag + Br$$

Silver sub-bromide = silver and bromine.

If, instead of bromide, we use iodide or chloride of silver, we get the same exchange. Thus:

$$2AgI = Ag_2I + I \quad \text{and} \quad Ag_2I = 2Ag + I$$
$$\text{or } 2AgCl = Ag_2Cl + Cl \quad \text{and} \quad Ag_2Cl = 2Ag + Cl$$

And during development

$$Ag_2I = 2Ag + I$$
$$\text{or } Ag_2Cl = 2Ag + Cl$$

Thus, all the atoms loosened by the light, but not separated from the silver, now become detached, and are dissolved in the developer, turning it to a brown colour.

We have now pure silver left, together with all the silver bromide which has not been altered by the light. This latter gives the plate a white colour on its reverse side. If at this stage the plate be immersed in the fixing bath, which may be done in broad daylight if all the developer has been washed off, the whole of the unchanged AgBr is dissolved out, leaving the reduced blackened silver on the now transparent film. This forms a reversed image, or negative, of the object photographed.

The above description appears delightfully simple, and one would imagine it can explain everything. Unfortunately for the theory, it is impossible, with our imperfect knowledge, to say exactly what does happen. We know that the light separates some of the bromine, for if we give a prolonged exposure with full aperture we can actually smell the bromine,

and if we test the solution during development we can prove its presence. In the same way we can show that chlorine escapes from silver chloride and iodine from silver iodide by the action of light and the developer. Moreover, we know that silver is left behind on the film after fixation.

The following experiments will give the reader some idea how complicated the problem is :—

If you dissolve some nitrate of silver in boiled distilled water and fill a transparent stoppered bottle with it, you may keep it in full sunlight indefinitely without its changing colour. If, however, you remove the stopper so that the air can get in, it will gradually become filled with black specks, and the inside of the bottle will likewise become blackened over. The air is always full of dust and traces of organic matter, and this will enter the bottle and cause the silver to be reduced round each particle. This becomes a focus for fresh deposit, and so more and more silver becomes reduced.

Now take some of the same solution of silver nitrate and paint a stripe on some white paper and place it under a negative in sunlight. In a few minutes you will notice the paper will have become a brown purple wherever the light has acted. In this way you can obtain a print—although destitute of gradations. You may treat a piece of paper with silver chloride in the same way, and it will change to violet and brown. In this case the salt loses its chlorine on exposure, just as the silver bromide lost its bromine.

We might write

$$4AgCl = 2Ag_2Cl + Cl_2$$

If, however, we analyze these products, we find that they did not completely answer to the above formulæ. We have remarked that an organic body of some sort is either absolutely necessary, or, if not, it greatly helps to effect the change. It is, therefore, obvious that the organic body must in some way modify the reaction.

If we put some pure silver chloride into the closed end of a bent tube while the other end is immersed in a bottle of distilled water, and the whole exposed for some days to sunlight and shaken from time to time, we shall notice that the water becomes purplish and rises in the tube. Moreover, the addition of nitrate of silver will give a precipitate of chloride of silver. This shows that an exchange of oxygen for chlorine

has taken place, which appears necessary to bring about the darkening. We must therefore modify our equation somewhat, and we may write

$$4AgCl + OH_2 = 2Ag_2Cl + HClO + HCl$$

And further experiments show us that oxygen, either from the air or combined with hydrogen in the aqueous vapour of the air, is necessary for the decomposition of the silver chloride, resulting in the formation of an oxychloride of a complicated nature, which some chemists express by the formula

$$\left.\begin{matrix} Ag_2Cl \\ Ag_2Cl \end{matrix}\right\} O$$

If we repeat the experiments with silver bromide or silver iodide, we shall find much the same sort of reaction takes place.

You must not imagine that the chemical change affects the whole of the silver haloid present on the film. It can only do this when the exposure is enormously increased beyond what is necessary to obtain a picture on development.

We can use either the iodide, the bromide, or the chloride of silver to form the sensitive emulsion, but it has been found that the chloride is not sensitive enough, and the iodide, although very sensitive to strong light is not so to weak light, while the bromide alone does not show enough "pluck" or gradation of tone. Hence, the platemaker adds a little iodide to his bromide. Since the silver haloids are insoluble in water it is necessary to introduce them very gradually in the form of iodides and bromides of potassium into a gelatine emulsion containing nitrate of silver. By this means an exchange between the haloids and the silver nitrate takes place which may be represented thus:

$$KI + KBr + 2AgNO_3 = AgI + AgBr + 2KNO_3$$

Potassium iodide and potassium bromide and nitrate of silver form silver iodide and silver bromide and nitrate of potash, so that the nitrate of silver is merely used to bring the silver in a convenient form to unite with the iodine and bromine.

Furthermore, it has been found that either prolonged boiling of the emulsion, or adding ammonia and leaving the emulsion to ripen for a day, greatly increases its sensitiveness; in other words, its rapidity.

I will now give a few experiments to show that the above

description by no means accounts for all the changes which take place.

Take a piece of paper and brush it all over with Japanese ink, and let it dry completely. Or procure an etching in Japanese ink, or an iron ink, or, in fact, any oxidizable ink such as many writing inks consist of. Place an ordinary gelatine dry plate in contact with it in the dark room, and keep it in the dark under slight pressure for, say, forty-eight hours. If you now expose the plate for the time necessary for a normal exposure and develop it, you will obtain a faint negative copy. The parts which were in contact with the light will appear as nearly clear glass, while the rest will be darkened.

It does not matter whether you first expose the plate to the light, and then keep it for two days in contact with the etching, or whether you keep it in contact with the etching first, and then expose the plate, either by itself alone, or in contact with the etching to the light. The result is the same. Since both the sensitive film and the ink were perfectly dry, it is clear that the ink did not stain the plate. Moreover, wherever the film was in contact with the ink, the hyposulphite fixing solution dissolved out the silver, and left clear glass, and this occurred no matter whether the plate was exposed to the light *before* or *after* the contact with the etching. Some change, therefore, must have occurred in the film itself.

Now place an unexposed dry plate in the fixing bath until all the silver salts are dissolved out, and when dry, put it in contact with the ink design for a few hours. No change is perceived either by transmitted or reflected light. But the moment you steam the film, or put it under water, the gelatine will swell out, wherever the ink has acted, and the design will appear in relief. Or, instead of wetting the film, pour a solution of silver nitrate over it. Wherever the ink has acted, a milky precipitate will be formed, and will be carried away by the solution.

If a piece of albuminized printing paper be placed on the ink, and treated with a solution of silver nitrate, and then exposed to light, the parts acted on by the ink will remain whiter than the remainder, which will turn purple-brown.

Evidently some compound is formed in the organic material, whether gelatine or paper, which is incapable of reducing the nitrate of silver. Now, the most oxidizable element in the film is its hydrogen. The ink causes the oxidation of the gelatine

or other organic body with which it comes in contact. This oxidation renders this part of the film incapable of being reduced by the developer, so that when the plate is put into the developer, the whole of the silver bromide is dissolved out at that spot, leaving clear glass. The hydrogen of the gelatine is all taken up by the oxygen, or ozone, through the ink, and is no longer available to unite with the bromide of silver.

Perchloride of mercury will act in the same way as the ink, but in this case it is the chlorine, instead of the oxygen, that holds the hydrogen a prisoner. A piece of wood, of almost any kind, cut across the grain and laid on a plate for some hours in the dark, will, on development, give a negative image of the grain. This, according to Dr. Russell, is due to the hydrogen peroxide which is formed.

The above shows us the important *rôle* which the organic layer, in which the silver salts are embedded, plays in the formation of the image.

When the light acts on the plate, a certain amount of the energy due to the waves of light succeeds in shaking loose some of the bromine and iodine atoms. But this is not all. The light acts on the gelatine menstruum, and starts freeing the hydrogen. Ordinary hydrogen will not affect a plate, but in the act of liberation it assumes the nascent condition, which is an extremely active form; in fact, it becomes "ionized," as it is called.

Then comes the greater energy of the developer, and completes the separation of the hydrogen, which immediately unites with the oxygen and the iodine, bromine (and chlorine, if present), for which it has greater affinity than the silver, so that the latter is left alone to itself, and forms the image.

Finally the hyposulphite dissolves all the salts out on which light has not effected any change.

Molecular Strain Theory.—In addition to the chemical theory, as briefly touched on in the preceding pages, two other theories are gaining acceptance, the one being based on physical changes, and the other on electrical changes.

The first is sometimes called the Molecular Strain Theory.

It is supposed that before the light has brought about a chemical decomposition of the silver salts, it has already caused a mechanical strain in the molecules, which renders them easily decomposed by the developer. The chief advocate of this theory is Prof. Chunder Bose of Calcutta University.

He has shown that a latent image may be formed, not only on sensitive plates, but even on inactive sheets of metal, and that these impressions are formed not only by the stimulus of ether waves, but also by mechanical stimulus. In fact, Bose has shown that metals respond to stimuli much in the same way that living muscle nerve preparations do, that certain drugs, such as strychnine, increase the excitability of metals and brings about a tetanus or spasm, while bromide of potassium lowers its activity, exactly as happens when we add a few drops of a solution to a photographic developer. If you take a metal stencil plate and electrify it while in contact with a dry plate, the image of the stencil will appear on development. If you do the same to the stencil when in contact with an uncoated glass plate, you will observe no change, but breathe over the plate and the image will at once be revealed. The effect of annealing either glass or metals greatly enhances their sensitiveness. Those of my readers who wish to follow up this theory cannot do better than consult his paper.[1]

Ionization Theory.—The second theory is called the Ionization or Electron Theory.

It has long been known that light and electricity are closely allied forms of energy, the velocity of light waves and those of electric disturbance being identical for the same medium, viz. ether. In all bodies an immense number of small electrically charged particles are present—called electrons—which, by their motion, produce electrical and chemical phenomena. Now, light waves have the power of discharging a negatively electrified body, and causing the negative electrons to escape from its surface, thereby setting up a positive charge in a previously uncharged body. This action tends to break up the molecules of the body into positive and negative particles. Each of these negative electrons is able to act on neighbouring molecules, attracting them to itself, and, as the process goes on, the substance acquires entirely new physical and chemical properties which, in the photographic film, are revealed by the action of the developer.

Many metals, notably zinc, platinum, and palladium, act freely on the bromide of silver in the film, when in the presence of hydrogen. This they accomplish by rendering the hydrogen active, *i.e.* by ionizing it, in which state it acts on the film in

[1] "Molecular Strain Theory of Vision and of Photographic Action," by J. C. Bose. *Photographic Journal of Great Britain*, June, 1902.

total darkness. This explains why damp is so injurious to films, since the oxidation produced by damp liberates ionized hydrogen, which sets to work to spoil the plate at once, and heat intensifies this action.

This is briefly the basis of the theory which has been elaborated by Joly of Dublin.

§ 97. **Practical Hints relating to Exposure and Development.**—If you wish to get perfect negatives, the following rules, the outcome of the author's personal experience, may prove useful:—

In the Field.—1. *Never allow daylight to fall on the plate-holder more than is absolutely necessary.* Don't keep the plates in the plate-holder more than two or three days if you can help it. The inside of the plate-holder may have a reducing or other injurious action on the plate. Never leave a naked slide about. Keep the slides in a leather case, or else in light-tight waterproof covers, which should have a flap held in position by an elastic band; this keeps the dust away. Whenever possible, draw the slide front under a focussing-cloth.

The best focussing-cloth is a brown waterproof cloth of light material, such as is used for dust capes. I use one made up into a large sleeve, 26 in. long, which is drawn together at one end by an elastic band sewn round the free border. It is made just large enough to slip over, and a little beyond, the focussing-screen. The other end should be partly slit open, and large enough to get your head in and allow of the slide being comfortably withdrawn. It should hang down about 14 to 18 in. beyond the camera. Such a sleeve is far preferable to a velvet focussing-cloth, which is apt to get blown about by the wind and soaked with rain.

Direct sunlight will penetrate any wooden back, in fact, you can print through a thin one by its action. Moreover, the sunlight will infallibly find its way through the slide chink if you do not insert the slide front perfectly squarely, unless you have a slide with two traps. In any case the slide should be periodically overhauled, to be sure it is light-tight, special attention being given to the velvet light trap. This wears smooth and leaks very readily.

2. If the wind is strong and the camera projects much beyond the tripod head, pass a piece of string round the baseboard and hold the end tightly against the ground with your foot during exposure. This will keep it steady. If you are

using a telephoto lens with long extension and only have a light folding stand, support the end of the lens with a rod. This can be made of wood or brass, terminating at the lens end in a crutch which supports the latter. The other end should be made to slide in an adjustable short tube hinged on to the front leg of the tripod. As soon as the lens is supported by the crutch, the rod can be fixed to the tube in which the other end slides by means of a screw. When not in use the rod can be fixed to one of the legs by spring clips. But the best plan undoubtedly is to employ a rigid stand, with a large solid head 5 or 6 in. in diameter. The legs should be each in one piece, or, at the most, have but one sliding piece, and the camera should be fairly heavy as well as rigid. Then you will not want a crutch.

3. Until you are able to judge the light value of any subject by the eye, which can only be done by long experience, use either Watkins' or Wynne's Exposure Meter, or one of the systematic exposure tables or guide books, such as "Wellcome's,"[1] which is, perhaps, the most complete in existence, and exceedingly reliable. It cannot be too strongly impressed on the beginner that correct exposure is the key to success, and although intensification and reduction will to some extent repair the evil, they can never do so entirely. For printing from negatives by gaslight, Dawson's Densitometer Box[2] is most useful. Failing that, a graduated printing frame, *i.e.* a frame with a row of sliding wooden slips, by which as many different exposures can be made on a print and all developed together, can be used.

4. In the Dark Room.—If you can help it, *never let the red light shine directly on the plate until development is nearly complete.* Of course you must hold the negative in front of the light to examine the image, but this need not be done until the image can be clearly seen while in the dish. You may use as much red, orange, or green *reflected* light as you please. It can rarely do any harm, provided the light itself is "safe." One sheet of deep ruby glass and one of reddish orange paper (two if oiled) is usually sufficient to make the light safe for ordinary rapid plates. The safest light of all is obtained by substituting for the ruby glass and paper a glass tank or trough with flat sides half

[1] Wellcome's "Photographic Exposure Record" (Burroughs, Wellcome & Co., London).
[2] Obtained at Houghton's or Fallowfield's.

an inch wide internally and filled with a six per cent. aqueous solution of bichromate of potash. This gives a fine light which cuts off the whole of the spectrum except the red and orange. According to Howard Farmer, it is 250 times as safe as an orange glass of the same colour and intensity.[1] For orthochrome, isochromatic, and panchromatic plates, either Lumière's special "Virida" screen, consisting of two sheets of yellow paper and two of the green, the former to be turned towards the light, or Wratten's green glass backed by yellow twill, should be used, and this light may be employed with confidence, *provided it is never allowed to fall directly on the plate for more than a few moments at a time.* According to my experience, red light reflected from a wall close at hand will not hurt a Lumière autochrome plate at all if allowed to fall on it obliquely. Nevertheless, an incredible number of plates are spoilt by light gaining access to them either before or after exposure.

5. *Never touch the film surface of the plate with anything except a pad of cotton wool or a camel's hair brush.*—Pretty well everything else will cause a mark on the plate on development. If you are uncertain which is the film side, hold the plate for a moment a few feet from the light, and the glisten of the glass side will show you at once.

6. You may develop either by time and factor number, or by examination of the image. The former is much the best way, at least, until you have had a great deal of practice. As development proceeds you may allow direct red light to fall on the plate, since it is becoming less and less sensitive every moment, and towards the end of development the negative may be held quite close to the light without risk.

7. Put all your glass measures and solutions in front of you and not at the side, and let some safe light fall on them, even when you are developing autochrome plates. You can then see what you are doing, and not make mistakes or knock the measures over.

8. *Always employ white glass or porcelain dishes.*—You can then be sure they are clean. The slightest trace of foreign matter will often cause stains on the plate. If you employ a Kodak developing tank flush it out before and after each operation.

[1] "The Illumination of Developing Rooms," Howard Farmer, *R. Photo. Journal*, March, 1900, in which the subject is very fully discussed. It contains an illustration of his bichromate dark-room lamp.

9. *Rinse out the measuring glasses and dishes each time before using them*, or leave them full of clean-water.

10. Be sure your solutions contain no particles in suspension. If necessary filter them. This is important when using tabloids and scaloids, especially such as carbonate of soda, permanganate of potash, and dianol, as the particles, unless quite dissolved, will inevitably produce oxidation or reduction spots on the plate. I find the intensifier used after the re-development of an autochrome plate is very liable to cause reduction spots unless this rule is attended to and the plate well rocked.

11. Pour the developer slowly over the plate, beginning at one end, or else brush the plate immediately afterwards with a broad soft camel's hair brush, so as to release any air bells and dust particles, otherwise you will get spots of clear glass, as they effectually prevent the developer from acting.

12. *Use all the baths of the same temperature.*—This should never exceed 70° F., but 58° F. to 65° F. is best. Variations of temperature profoundly affect development, and tend to cause frilling. Watkins, in his latest pamphlet, has shown how to calculate for variations of temperature.

13. *Use fresh developer.*—The fixing solution will keep indefinitely, so will the bromide, but most developers oxidize and turn brown in the air. This is especially the case with pyrogallic acid solutions. If you are afraid of staining your fingers with this developer, use finger stalls.

14. *Don't neglect the alum and citric, or chrome alum, bath in hot weather*, or else use ice to cool all the solutions. This will protect the film from injury and frilling. The alum should be used immediately after development, and before fixing. After immersion in this bath the plate will be quite safe even to broad daylight for a short time. In the case of autochrome plates, if they tend to frill, give them a two per cent. formalin bath (Schering's formalin, diluted 1:20 of water) for one minute before development. This hardens the film and prevents circular blisters, which usually crack and let in the water. The latter dissolves some of the green dye, and causes large green discs or patches which quite ruin the picture.

15. *As far as possible keep to one developing formula and master it.*—The formula found on the plate box is generally as good as any for that brand of plates. If you change about from one developer to another you will never know the printing value of

your image, which can only be learnt from experience. Films are tricky things and by no means so reliable as plates, therefore, for important subjects, prefer plates.

It follows from this that when you have hit upon a brand of plates which give you first-class results, keep to it. Besides, until you know your plate thoroughly you are never sure of your exposure.

16. *Over-exposure.*—Keep a ten per cent. solution of bromide of potassium on the shelf in front, so as to restrain the activity of the developer in case the image flashes out too quickly. This, if neglected, will result in a veiled, or, at any rate, a dull flat negative without gradations. Perhaps the best way to avoid this is to *instantly* flush the plate with water the moment you perceive the image flashing out, otherwise it will be too late. Then leave the plate protected from the light under water while you prepare some fresh developer with three times the normal quantity of bromide, very little alkali, and an excess of pyrogallic acid or whatever developer you may happen to be using. Then develop fully. This allows the shadow details to gain in strength more than the lighter tones, thereby increasing contrast. You can always reduce the density afterwards, if necessary. Of course, if you have reason to suspect over-exposure, you must start with a modified developer, as above suggested.

17. *Under-exposure.*—If the plate is under-exposed or "chalky," or if parts refuse to develop up, pour off the developer, cover up the negative, and prepare a fresh developer *without bromide* and diluted with three or four times as much water as before. Then cover over the plate with the solution and leave it to develop for a quarter of an hour or more, examining it every two or three minutes. This method allows the shadow details to acquire strength and depth before the high lights get too dense, with the result that the negative loses its chalky character, and a softness and range of gradations are secured.

Under-exposure can be remedied, if it be not less than one half the normal time. Over-exposure may be controlled up to four, or in some cases eight or even ten times the normal, and a good negative obtained with patience and judgment in both cases; but, as I have said before, no after treatment can quite repair the damage done by wrong exposure.

18. *Use plenty of developer.*—I use $1\frac{1}{2}$ oz. for a quarter-plate, 2 oz. for a 5×4 plate, 3 oz. for a half plate, and 4 oz. for a whole plate. Rock the dish both ways for the first 10 or 15 sec.,

or until the first sign of the image appears in the border line, then cover the plate up and continue rocking. If, on pouring over the solution, part of the film still remains dry from a blister or bubble, after the lapse of 4 to 5 sec. the negative will be irretrievably ruined, as no amount of doctoring will remove the stain entirely,

19. If you use autochrome plates you cannot be too careful about excluding dust and bubbles from the film side of the plate. They are sure to spoil the plate, since you can't, by any artifice, quite hide the spots afterwards.

20. Negatives should be washed in tanks or, at least, in an upright or slanting position, and not lying flat in a dish, and (unless in the case of autochromes) for not less than half an hour. Autochrome negatives must not be washed for longer than 5 or 6 min. and only under a very gentle stream to avoid cracks in the film.

§ 98. **Development of the Plate.**—After exposure take the plate to the dark room and place in a clean dish film side upwards. Pour the developer steadily over the plate, with enough light to see that the plate is quite covered without "islands." Notice the exact time by the second-hand, and gently rock the plate a foot or two away from the red light until the image begins to appear. This is known by the rebate margin of the plate (which received no image) becoming just visible. At once note the time, and cover up the dish, but continue rocking. The number of seconds which has elapsed since the developer was poured on, multiplied by the factor number of the developer, will give the correct time for development. This factor number is a constant, and will be found under the head of each developer in Table 17.

Thus, suppose twelve seconds between pouring on the developer and the first appearance of the image, and the factor number is ten. Then the correct time for development will be 12 sec. × 10, or 2 min.

The two following developers are examples of reliable ones which can be used with any plate except the autochrome :—

(1)

Pyrogallic acid	27 grains	or	1,75 grammes
Metol	22 ,,		1,5 ,,
Metabisulphite of potash	60 ,,		3,9 ,,
Bromide of potassium	10 ,,		0,65 ,,
Distilled water (or boiled)	10 fluid oz.		280 c.c.

(2)

Washing soda	2 oz.	or 56,7 grammes
Distilled water (or boiled)	to 10 „	280 c.c.

No. 1 should be in a stoppered bottle; No. 2 in a corked bottle (as a stopper will stick fast).

For use take equal parts of 1 and 2. This gives vigorous dark negatives. Factor number, 9.

If you do not wish to stain the fingers, keep them wet and use

(1)

Metol	25 grains		1,6 grammes
Hydroquinone	20 „		1,3 „
Sulphite of soda	240 „	(½ oz.)	15,6 „
Distilled water (or boiled)	10 oz.		280 c.c.

(2)

Bromide of potassium	12 grains or	1,6 grammes
Carbonate of soda	240 „	15,6 „
Water (distilled or boiled)	10 oz.	280 c.c.

Use equal quantities of 1 and 2. Factor number, 10.

To reduce contrast (with either developer) use less of No. 1 and add more water (say half an ounce to one ounce more water to each ounce of developer). To increase contrast use more of No. 1 and less of No. 2, and add 10 to 20 drops of a 10 per cent. solution of potassium bromide to each ounce of developer.

§ 99. **Reduction of the Image.**—Many negatives are greatly improved by judicious reduction. Thus, if a negative is too dense to print well or quickly, it may be reduced slightly all over, and then further reduced locally by means of a paint-brush dipped in the solution, but the part must be washed quickly afterwards. A preliminary print will guide the beginner as to what parts need local reduction. Again, a negative may be veiled with a general fog which can readily occur when light has had access to the plate, or, when it has been over-exposed or over-developed. Such a negative will print out flat and lifeless. By reduction much of the surface silver can be dissolved away, so that the shadows become nearly clear

glass, and at the same time the high lights get less opaque. By subsequent intensification the printing quality of the middle tones and high lights will be still further improved. In this way a brilliant, "plucky" negative can be obtained from a flat one. It is better to over-develop than to under-develop a plate, since if you under-develop you lose detail which can never be recovered, but you can generally reduce a considerably over-developed one to a good printing negative.

The two best reducers I know of are Welborne Piper's modification of Howard Farmer's solution, and the persulphate of ammonia reducer. The former consists of equal parts 10 per cent. solutions of potassium ferricyanide and potassium bromide mixed. To use, cover the plate with a measured quantity of fresh hypo, and to each ounce of hypo add a drachm of the above mixture. Rock the dish all the time. The reducer acts very slowly at first, but after a minute or so with increasing rapidity, so the negative must be carefully watched and repeatedly examined. Flush with water the moment the reduction appears sufficient. A white porcelain dish is best, as it enables you to watch the progress of reduction by its increasing transparency without holding it up to the light. This mixture reduces the image in a very even manner without injuring the half-tones, and increases contrast.[1]

The ammonium persulphate is sold in tubes, or in cartons, each holding 25 tabloids. For use, dissolve 30 grains of the salt in 2 to 3 oz. of water. Pour the solution over the negative, rock the plate and watch it carefully. Wash the negative well for a quarter of an hour afterwards to prevent further action. This reducer is not so useful as the former for over-exposed negatives, since it attacks the dense portions more than the lighter ones, but this quality is just the thing for dense, under-exposed, normally developed negatives, or for over-developed negatives which print with hard contrasts which need diminishing.

§ 100. **Intensification of the Image.**—If the negative is thin and wanting in contrast, it should be intensified. This latter process is more uncertain and risky than reduction. In the first place you must fix completely, and then *eliminate every trace of hypo*, or you will get markings. If you have but little experience, use either a uranium or a chromium intensifier. These are far the simplest for the beginner, and one can repeat

[1] See *British Journal of Photography*, April 24, 1908.

the process or re-develop if the density is still weak, without risk to the plate. Uranium leaves a brown image. Another good receipt is Monkhoven's perchloride of mercury solution followed by cyanide of silver, but it needs judgment and great care. It gives a black image. If the negative is flat or veiled by thin fog it may be got rid of by first reducing with Piper's modification of Farmer's solution (as stated in previous paragraph), and then intensifying at once as soon as the hypo is quite eliminated, and while the plate is wet. A flat negative may be turned into one with brilliant contrasts in this way.

The method for uranium intensification is as follows :—

Take of	Potassium ferricyanide	1 gramme
	Uranium nitrate	1 „
	Glacial acetic acid	10 c.c.
	Water	100 „

Well wash the plate and pour over sufficient solution to cover. Rock the plate, and examine in daylight from time to time. When sufficiently dense rinse *quickly* and leave to dry. If found too dense it can be reduced by washing in alkaline tap water. To hasten the reduction add a pinch of carbonate of soda to the water. By painting a solution of carbonate of soda with a camel's hair brush, local reduction can be effected.

Chromium Intensification. — This is largely due to the researches of Welborne Piper and Carnegie, who have placed it on a scientific basis and shown how certainty and uniformity can be secured by using definite proportions of acid and bichromate. There are two ways of using the intensifier. First, by bleaching in a solution of hydrochloric acid and bichromate of potassium, and then re-developing the image by any clean developer, such as metol-quinol, glycine, etc. Second, by using Wellcome's chromium tabloids, sold in carton packets of twenty-five. This greatly simplifies the process, and we strongly recommend it to the beginner. For use, dissolve one tabloid in two ounces of water (sufficient for a quarter-plate). Pour over the plate and rock until the negative is bleached throughout, wash in running water for a minute, and pour gently on and off a solution of one tabloid of metabisulphite of potassium to two ounces of water until the yellow stain has disappeared. If you wash well for a quarter of an hour you can omit the metabisulphite altogether. Then re-develop with pyro-metol-quinol, or your favourite

developer, for three to five minutes, until sufficiently dense; by slightly reducing and then intensifying in this way very brilliant lantern slides can be made.

Monkhoven's method is as follows:—Wash the negative for half an hour in running water, or else soak in a hypo eliminator for a few minutes and wash well. Prepare two solutions—

(1)

Perchloride of mercury	2 grammes
Pure hydrochloric acid	1 c.c. (mix and add)
Distilled water	100 c.c.

(2)

Silver nitrate	4 grammes
Distilled water	100 c.c. (add slowly)
Potassium cyanide	4 grammes dissolved in 100 c.c. distilled water

These solutions keep indefinitely if kept from the air in stoppered bottles.

Place the negative on a porcelain dish and cover with Solution 1. Rock occasionally. When the negative is just bleached, pour the solution back into the bottle. Wash the negative in running water for a few minutes, place in a clean dish, and pour over Solution 2. When the negative appears uniformly black, pour the solution back into the bottle, well wash and dry. Or, instead of Solution 2, use in the same way crystallized sodium sulphite 15 grammes, water 100 c.c. This solution is not so strong an intensifier as Monkhoven's, but either may be applied over again if the density is insufficient the first time. The success of the result depends largely upon the complete elimination of hypo by thorough washing, and of all traces of the solutions used, by similar treatment afterwards.

CHAPTER VII

THE OPTICAL LANTERN

The optical lantern is essentially a microscope in which the magnified image is projected on to a screen instead of being observed through an eyepiece. It consists of three parts—

(1) The source of illumination, called the radiant or luminant;

(2) The condensing system;

(3) The projecting system.

§ 101.—(1) **The Radiant.**—The radiant employed should be as *bright and as small as possible.* From optical considerations this is important for very critical work. Still, there can be no doubt that either one or two acetylene jets placed close one *behind* the other, an alcohol vapour lamp, or a gas jet with Welsbach thorium or zirconium mantle, are effective.

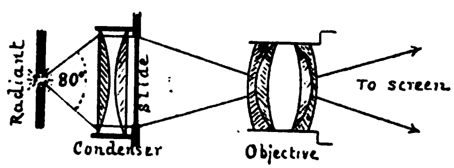


Fig. 174.

Still more powerful is the Nernst electric light, with one, two, or three incandescent rods. Either the central rod or all three may be used, but never the central and one lateral rod, otherwise a double image will result, as I have found to my cost. The rods require to be connected up with the current from the main. Several kinds are made, viz. a form for the continuous, and one for the alternating current. If you have the former current they will ignite automatically, otherwise you will have to heat the rods with a spirit lamp first. Also a lamp adapted for 110 volts and another one for 210 volts.

Hence, care must be taken to select the right one, as the same lamp will not do for either, and from what we have just stated, you must know which of the four kinds you require. The best form of illuminant is undoubtedly the electric arc, since it best fulfils our first condition; either an alternating or a continuous current connected with the main may be used. The carbons should be inclined at about 90° to each other, so as to keep the dull negative carbon as much out of the way of the light as possible. Next to that, the mixed jet, and the blow-through oxyhydrogen jet turned on to a *hard* lime or zirconium cone, gives the best light. Lastly, there is the thorium mantle fed with alcohol vapour, which is pumped up from time to time by a Higginson's syringe in an indiarubber force pump attached to a rubber tube. This gives a very fine, steady light of about 350 candle-power. Paraffin lamps, owing to their low degree of luminosity, large surface of flame, and great heat, are only used in the cheaper form of lantern.

§ 102.—(2) **The Condenser.**—This usually consists of two plano-convex lenses placed with their convex surfaces nearly touching. Its function is to convert the divergent rays of the radiant into a parallel or slightly convergent beam, and to illuminate the transparency as equally and intensely as possible. If no condenser were used, the picture on the screen would only consist of that portion of the slide which lay in the cone of rays LAB (Fig. 175) from the radiant to the lens, probably not exceeding the area of a penny. All the other rays which passed through the slide, such as are indicated by C and D, would miss the lens altogether.

For small objects or slides such as are used in microscopic projection, a triple combination (Fig. 176), such as originally designed by the late Traill Taylor, is to be preferred, as the smaller front meniscus lens converges the light to a small area and embraces a larger angle (about 90°, compared with 75° or 80° in the double condenser); but it is considerably more expensive than the simpler form, and the latter is almost universally used. The firm of Dallmeyer produce a special form of double condenser for projection purposes which is made from carefully selected glass, and the lenses are free from striæ and bubbles.

Triple condensers are also recommended when the screen is a long distance off, as in concert halls, etc., since the

meniscus back lens allows of the light being placed closer, which is an advantage.

The double condenser should not be less than $4\frac{1}{4}$ in. in diameter for the English slide, or $4\frac{4}{5}$ in. for the Continental, *i.e.* of such a size that the inscribed square must never be smaller than the slide to be illuminated, which is invariably 3×3 in. in England and usually $4 \times 3\frac{1}{4}$ in. (10×8 cm.), or

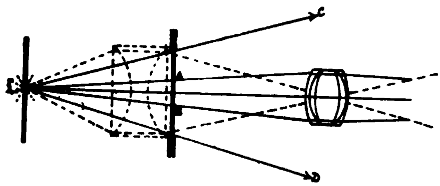


FIG. 175.

else $3\frac{1}{4} \times 3\frac{1}{4}$ in. (8,2 × 8,2 cm.) on the Continent. The standard American slide is $4 \times 3\frac{1}{4}$ (sometimes $4\frac{1}{4} \times 3\frac{1}{4}$ in. = English quarter-plate).

It is preferable to have the condenser somewhat larger than $4\frac{1}{4}$ in., so that the marginal rays, which are the cause of the objectionable orange fringe round the disc on the screen, pass outside the slide and are lost. Now that the direct method of taking coloured positives has become a fairly easy and practical

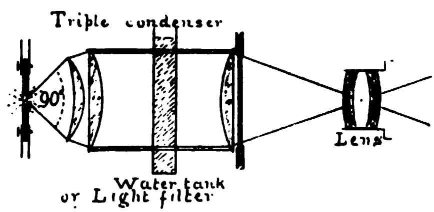
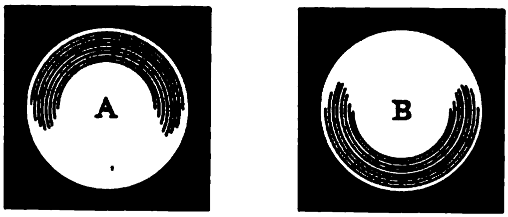


FIG. 176.

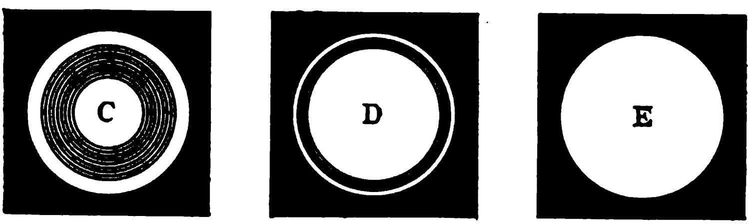
fact, it would be well if lanterns were made with condensers which would cover a quarter-plate without cutting down. In other words, a $5\frac{1}{2}$-in. condenser and a quarter-plate carrier should be fitted, but Hughes' plan of using a square condenser slightly larger than the slide is the best, as it takes up less room and gives an evenly lit image up to the margins. The condenser should have a back focus of $2\frac{1}{2}$ or 3 in., and be placed at that distance from the radiant, so that the refracted rays are nearly parallel. I would suggest that an ornamental

transparent, coloured frame, photographed on a thin piece of glass, should be placed immediately in front of the diapositive in a separate slot in the carrier, but in contact with it. In this way the picture would have the agreeable finish which every one admires in an oil painting, when placed within a wide gilt frame.

It is important that the lenses of the condenser fit loosely in the mount, *i.e.* one should be able to rotate them easily with the fingers, otherwise they are apt to crack with the heat. For



Light raised too high. Light too low down.



Light too near condenser. Light too far from condenser. Correct appearance.

FIG. 177.—Appearance of the disc on the screen when the radiant is in various positions. Copied by permission from Bishop's "Art of Projection," p. 24.

the same reason, if Lumière colour slides are projected, it is advisable to have a narrow tank filled with a nearly saturated solution of alum placed immediately in front of the condenser, if possible in contact with it. Messrs. Zeiss supply a glass tank only $\frac{1}{8}$ in. wide, with true surfaces, for five shillings, which answers the purpose admirably. A thicker tank than this will cause the corners of the slide to be cut off, since the rays converge on issuing from the condenser. Hughes makes an excellent glycerine tank, applied in the same way. Perken & Son have, at my suggestion, designed a lantern with extra

large condenser ($5\frac{1}{2}$ in.) and alum tank, which answers admirably for quarter-plate Lumière colour slides.

In practice it is found that in order to get the best results, the focal length of the condenser should be proportional to the equivalent focus of the objective. It is also essential that the brightest part of the flame should be accurately centred in the axis of the condenser, and furthermore, that the distance of the radiant from the condenser should be so adjusted (which can only be done by trial) that the coloured ring formed round the illuminated disc on the screen disappears. The disc should then be uniformly white and quite free from colour. To get this perfect requires some practice in adjusting and centering.

If the light be above the principal axis of the condenser, the dark coloured semicircle, A, will be seen on the upper margin of the disc (Fig. 177). If below, the half-ring will be near the lower margin, B. Should the light be too near the condenser, a complete dark ring, with a bluish fringe, will be seen occupying the middle third of the disc C. If the light be too far away, the ring will have a bluish fringe and will surround the periphery of the disc D. If both centering and distance be correct, the disc on the screen will appear uniformly white. In order to increase the light, a convergent mirror is sometimes placed behind the luminant, which should be placed at its focus.

§ 103.—(3) **The Projecting System.**—This usually consists of a 6-in. or 8-in. focus Petzval portrait lens. Perken

FIG. 178.—Perken & Son's Lantern Lens.

& Son have produced an excellent form at a very low price (Fig. 178), but one of the many forms of rectilinear anastigmats of large working aperture, F/4 to F/5, is to be preferred, as they have a flatter field and, consequently, a better marginal definition. Still the Petzval form performs well enough for any ordinary exhibition, and is much cheaper.

The positions of the lenses are marked in the above figure, which will guide the amateur in putting them back, if removed for cleaning.

The Portrait Anastigmat, Planar, and Unar lenses of Zeiss and Ross, the Cooke lens, Dallmeyer's Portrait Stigmatic, and Busch's Anachromat, Beck's Unofocal and No. 2 Extra Rapid Rectilinear are suitable for this purpose, and give superb images. Dallmeyer & Co. make a special projection lens of very flat field (Fig 179). Beck has lately introduced a multifex objective, which, by simple separation of the lenses in a draw tube, will produce any focus from 6 in. to 20 in. Perken & Son have also introduced a similar lens on the telephoto principle. The definition of the image depends far more on the perfection

FIG. 179.—Dallmeyer's Lantern Lens.

of the lens than on the condenser, although bubbles in the latter are apt to show on the screen, which they will not do in the lens.

The Screen.—The best form of screen is undoubtedly a whitewashed or distemper-coloured wall. For ordinary sitting, 20 ft. long, one 6 ft. square is ample. For a room 30 ft., an 8-ft. screen is best. For a room 50 ft. long, a 10-ft. screen is about right, and so in proportion. In private houses it is a good plan to have the screen made of stiff twill or linen, and rendered quite opaque with two coats of white paint, to which a trace of black or blue may be added, sufficient to slightly tone down the glare of the white. Ordinary cotton sheeting lets too much light through. If, however, it be thoroughly

wetted and the room is long enough to allow of the lantern being placed behind, the result is extremely satisfactory. The screen can be fixed to a roller, actuated by a spring, which rolls up automatically underneath the cornice when not wanted. It can instantly be pulled down by a cord when required. Bamboo frames, largely advertised, are a great nuisance. For microscopic projection, tracing paper, which can be obtained in widths of 5 ft., is excellent, and the image can be seen from behind.

§ 104. **Formulæ and Calculations.** — The size of the image on the screen, the distance of the screen, the focal length of the lens, and the size of the object whose image is thrown on the screen, can at once be calculated by the ordinary rules of conjugate foci.

Let F = focal length of the objective ;
O = diameter of the slide (usually 3 in.) ;
D = diameter of the disc ; and
C = conjugate distance of the lens from the screen.

Then we obtain a simple formula from which the other three are derived by merely transposing the terms.

The formula is $C = \frac{D.F + F}{O}$, but since F is small compared with D . F, we may give it as

$$C = \frac{D.F}{O} \quad . \quad . \quad . \quad . \quad . \quad . \quad [84]$$

Therefore, the rule, which is near enough for all practical purposes, *to find the conjugate distance of the lens from the screen*, multiply the diameter of the disc by the focal length of lens and divide by 3.

$D = \frac{C.O}{F}$, *or, to find the diameter of the disc*, multiply the distance of the lantern from the screen by 3 and divide by the focal length.

$F = \frac{C.O}{D}$, *or, to find the focal length of the lens*, multiply the distance of the lantern from the screen by 3 and divide by the diameter of the disc.

$O = \frac{D.F}{C}$, *or, to find the size of the object used instead of an ordinary slide*, multiply the diameter of its image by the focal length of the lens, and divide by the conjugate distance of the lantern from the screen.

Example.—How far must the lantern lens be removed from the screen to give an 8-ft. picture, the focus of the lens being 6 in.?

Since $$C = \frac{D.F}{O},\ C = \frac{96 \times 6}{3} = 16 \text{ ft.} \quad \textit{Ans.}$$

Having a 25-ft. working room at our disposal, what lens is to be used to give a 9-ft. picture?

Since $$F = \frac{C.O}{D},\ F = \frac{25 \times 12 \times 3}{9 \times 12} = 8\tfrac{1}{3} \text{ in.} \quad \textit{Ans.}$$

What is the diameter of disc projected by a 5-in. lens at a distance of 18 ft.?

From the formula $D = \frac{C.O}{F}$ we obtain

$$D = \frac{18 \times 12 \times 3}{6} = 9 \text{ ft.} \quad \textit{Ans.}$$

How large will the image of a fly, $\frac{1}{4}$ in. in diameter, appear on a screen 30 ft. away, the objective being one of 3-in. focus?

Here $$D = \frac{30 \times 12 \times 0{,}25}{3} = 2 \text{ ft. } 6 \text{ in.} \quad \textit{Ans.}$$

Lastly, the image of a cheese mite projected on to a screen measures $2\frac{1}{2}$ in. The objective is $\frac{5}{8}$ in. and the screen 25 ft. away. What is the size of the mite?

From the formula

$$O = \frac{D.F}{C} = \frac{2\frac{1}{2} \times \frac{5}{8}}{25 \times 12} = \frac{1}{192} \text{ in.} \quad \textit{Ans.}$$

Since the slide is nearly always 3 in. in diameter, the foregoing formulæ can be simplified to

$$D.F = 3C \quad \ldots\ldots \quad [85]$$

in which F is always in inches and C and D in feet. Inasmuch as C and D are on opposite sides of the equation the reduction to inches is unnecessary.

Note.—If a more exact formula be required (which is only necessary for Examination purposes), we must add F to the result, making the equation

$$D.F + F = 3C \quad \ldots\ldots \quad [86]$$

The slide is placed close to the condenser, between it and the lens, and should be inverted, so that the image on the screen may be erect.

§ 105. **Method of Projecting Opaque Objects.**—In order to project the image of an opaque object, it should be placed on a horizontal board below the condenser, and illuminated by a mirror placed in the path of light inclined to the object at an angle of 45°. The lens must be placed vertically above the object and the image reflected by a second mirror on to the screen.

§ 106. **Method of Projecting Horizontally Placed Objects.**—To exhibit a transparent object, such as a flat glass tank containing water, fish, animalculæ, etc., which requires to be placed in a horizontal position, a similar adjustment can be used; but a third mirror must be placed beneath the transparent object (Fig. 180), and the light reflected from

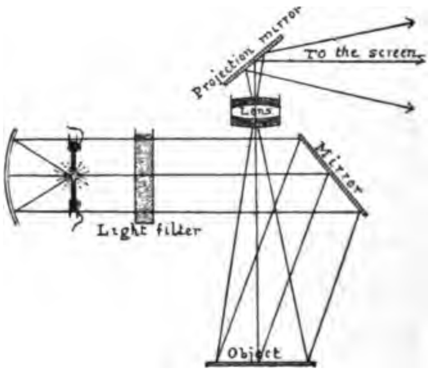


FIG. 180.

the first mirror along a path *outside the object* on to the second, and from it reflected vertically upwards through the object and lens, from whence it is reflected on to the screen by the third mirror. To exhibit such a phenomenon as falling water or rising smoke, an erecting prism must be placed in front of the lens, otherwise the water would appear to ascend, and the smoke to descend, on the screen.

For methods of projecting views in stereoscopic relief on to a screen, see my book on the Stereoscope and Rangefinder.

§ 107. **Epidiascope.**—The epidiascope made by the firm of Zeiss is the most complete apparatus that exists for projecting images of every kind. It is, however, very large and cumbersome, about $4\frac{1}{2}$ ft. in height by $2\frac{1}{2}$ ft. in length, and as

PLATE XIII.

FIG. 181.—Hughes' Scientific Demonstrating Lantern for Institutes and Colleges, arranged with erecting prism.

H, Hand wheel to regulate the length of arc.
P, Reflector adjustment.
T, Door of cooling chamber.
St, Wheel for coarse focussing.

S, Sliding door to stage.
B, Lever which regulates the inclination of mirror.
K, Fine adjustment.
N, Adjustment regulating inclination of erecting mirror.

FIG. 182.—General View of the Zeiss Epidiascope.

FIG. 186A.—Professor Dimmer's Camera for photographing the Fundus Oculi. (*By permission of the inventor.*)

heavy as an upright piano. In its cheapest form it costs about £60, and complete with lens, fine focussing movement, adjustable erecting mirrors, and Berger's changing appliance, etc., about £80. The objective alone costs £16.

For those who can afford it, and are fortunate enough to possess a special room for exhibitions, it is undoubtedly superior to anything in the market. A searchlight lamp with a current of 30 to 50 amperes is used, which will fully illuminate a 3-in. slide up to 37 diameters on a 10-ft. screen. The accompanying

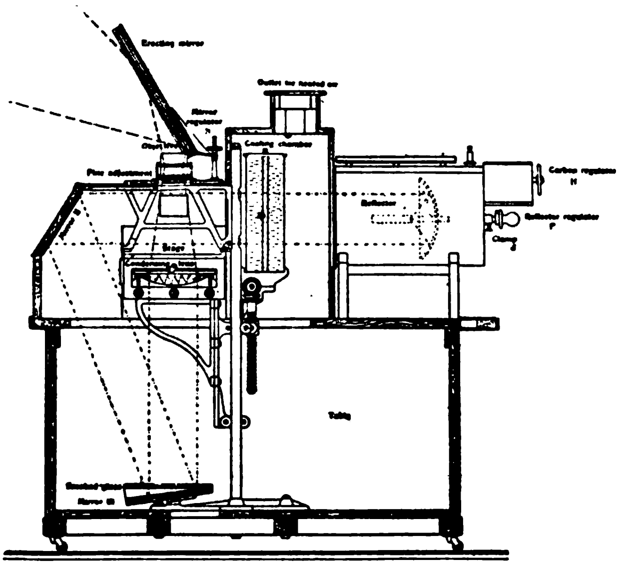


Fig. 188.—Epidiascope, with fixed erecting mirror showing the path of rays by reflected light for projection of opaque objects.

three illustrations will give a better idea of the instrument than any description.

Hughes has quite recently brought out a small and very portable lantern by which opaque objects such as picture postcards and photo prints can be projected. The object is brightly illuminated by a pair of Luna electric burners or, if preferred, by two mantles fed by compressed alcohol vapour. No condenser is needed. The objective is placed at $F + \frac{F}{16}$ from the object for a 4-ft. picture, which is the largest size he recommends for good illumination.

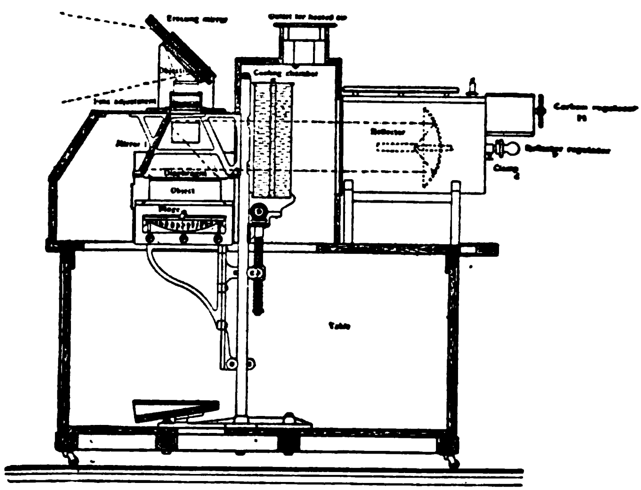


FIG. 184.—The same, with adjustable erecting mirror for the projection of transparent objects by transmitted light.

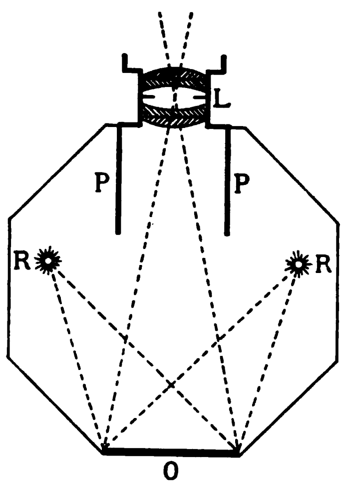


FIG. 185.—Hughes' Lantern for Opaque Objects. L = lens, O = the opaque object, PP = partition screens to cut off direct light from the radiant RR, RR = the two Luna burners.

§ 108. **Method of Photographing the Back of the Eye.** —If a narrow beam of rays passes through any number of media and finally strikes a plain reflecting surface at right angles to its direction, the beam will be reflected back along its original path. If, therefore, a darkened chamber has only a single small window, and its interior be lit up by a light on the outside, it will be impossible to see anything inside the chamber unless the observer can place his eye somewhere inside the emergent cone of rays. This is the explanation of the black pupil of the eye, which corresponds to the window. The best way to see inside the chamber is either to use a reflector having a central perforation to project the light in,

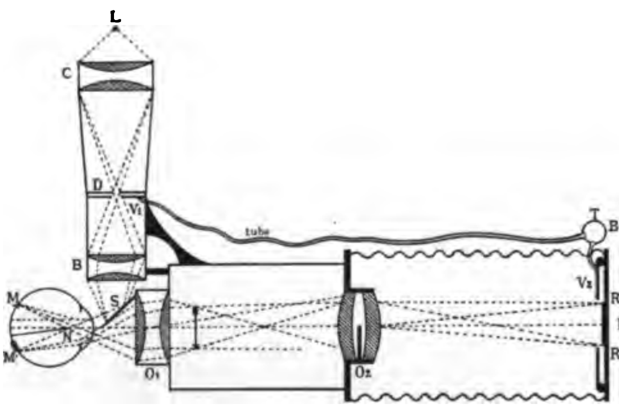


FIG. 186.

and perceive the returning beam through the aperture, or to use a very small mirror, and keep one's eye close to its edge so as to catch a portion of the reflected light. It was this principle which Helmholtz adopted in his ophthalmoscope. Dr. Thorner elaborated this instrument so as to form an adjustable and rigid instrument which can be focussed mechanically. Professor Dimmer of Graz has still further improved the apparatus, whereby an enlarged photograph of the fundus oculi can be secured in a small fraction of a second (Fig. 186). The apparatus is as follows :—

L is a powerful source of light, preferably an arc light; C is the condenser; D, a diaphragm on the image plane. From this diaphragm the rays pass through the collecting system,

B, on to the plane mirror, S, from whence they are reflected through the upper part of the pupil of the eye, and crossing around the nodal point, N, illuminate a large area of the back of the eye (retina and choroid). This forms the bright object to be photographed, which in the case of the human eye forms a bright concave orange-red mirror, MM. The system of lenses is so arranged that the rays which enter through the upper half of the pupil emerge through the lower half of it, and are collected into a convergent beam by the condenser, O_1, to the Zeiss planar objective, O_2. This lens brings the rays to a sharp focus at R, where the sensitive isochromatic plate is inserted. The whole of the space between O_1 and R is, of course, surrounded by a box and bellows, which form the camera.

The shutter V_1 lies immediately behind the diaphragm D, while the second shutter, V_2, which is in the form of a roller-blind, lies just in front of the plate, P. By means of a small mirror (not represented in the figure) the fundus image can be observed up to the instant of exposure. A squeeze of the ball T causes the image to flap up, and at the same instant both shutters, controlled by a single wire, are opened and closed by an electric current.

The front part of the apparatus between O_1 and O_2 is never altered. The focussing necessary owing to errors of refraction of the observed eye is got by racking the focussing-screen R in or out. The position of the eye to be examined is assured by getting the patient to fix the image of a flame in a mirror placed before him with his other eye. The original negatives show a magnification of 3 diameters, which can readily be enlarged without loss of detail 3 or 4 times more, so that one can obtain a sharp picture of 10 to 12 times the original.

In Professor Dimmer's hands this method of securing photographs of the fundus oculi has been most successful, in fact, his photographs have never been equalled.

The five magnificent photographs shown on the accompanying plate are reproduced from Dr. Dimmer's untouched negatives, with his kind permission. They show not only the healthy eye, but portray various lesions and diseases with great fidelity and minuteness of detail. Seeing that a photographic record can thus be secured by an exposure of a mere fraction of a second, his method will undoubtedly become a necessary part of the equipment of every ophthalmic clinic.

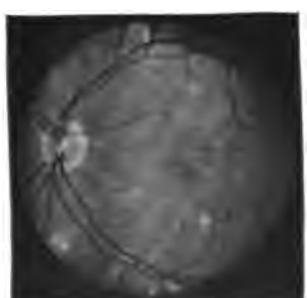
PLATE XIV.

Conus; choroiditis at the macula
M = 9D. [108]

Colloid excrescences in the pigment epithelium layer
(Senile change, man 80 years).
[188]

Normal fundus
(Man 40 years old). [26]

Retino-choroiditis. [24]



Choroiditis. [338]

Photographs of the Human Fundus Oculi.
(Printed by permission from the original photographs of Professor Dimmer of Graz.)

To face p. 278.]

APPENDIX

§ 109. Tables.—

1. TABLE OF ILLUMINANTS.

Nature of illuminant.	Colour of light.	Nature of spectrum.	Intrinsic brilliancy.
Paraffin or wax candle.	Yellow .	Yellow rays predominate	4% per sq. in.
Acetylene gas	White .	Resembles sunlight	75 to 100 candle-ft. per sq. in.
Coal gas batswing burner	Yellowish-white	Green rays predominate	20 to 40 candle-ft. per sq. in.
Coal gas mantle . . .	White .	Yellow and green rays predominate	40 to 60 candle-ft. per sq. in.
Incandescent lamp . .	. . . .	Yellow and orange predominate	200 to 300 candle-ft. per sq. in.
Metallic filament . .	White .	. . . .	400 to 600 candle-ft. per sq. in.
Nernst lamp	White .	. . . .	1000 candle-ft.
Mercury vapour . . .	Greenish-yellow	No red rays, only green & blue rays	5 to 10 candle-ft.
Moore tube light. . .	Rose-orange		
Oxyhydrogen blow-through coal gas jet.	White .	Resembles sunlight	150 to 200 candle power.
Oxyhydrogen mixed pure hydrogen jet .	White .	Resembles sunlight	250 to 300 candle power.
Magnesium wire. . .	. . . .	. . . .	100 to 150 candle power.
Arc light from house current	White .	Resembles sunlight	300 to 600 candle power.
Direct sunlight . . .	. . . .	. . . .	60,000 candle power.

2. Dr. MIETHE'S TABLE OF LIGHT INTENSITY FOR VARIOUS ANGLES OF VIEW.

(*The angle is measured from the centre of the plate.*)

Angle.	Light.	Angle.	Light.	Angle.	Light.
0	1,00	20	0,76	40	0,34
5	0,98	25	0,67	45	0,25
10	0,94	30	0,56	50	0,17
15	0,87	35	0,46	55	0,11

3. REFLECTING POWER OF VARIOUS MATERIALS.

Material.	Coefficient of reflection.
Highly polished silver	0,92
„ „ brass	0,70-0,75
„ „ copper	0,60
Ordinary mirrors and various polished metals	0,40-0,70
White blotting paper	0,82
„ cartridge paper	0,82
Yellow-painted wall, clean	0,40
„ „ „ dirty	0,20
Emerald-green paper	0,18
Dark brown paper	0,13
Vermilion, blue, green, cobalt-blue paper	0,12
Black paper, dull	0,05
„ cloth	0,012
„ velvet	0,004

4. TABLE OF ADDITIVE COLOUR EFFECTS, OR COLOUR SYNTHESIS (HELMHOLTZ).

Colour.	Violet.	Indigo.	Cyan-blue.	Blue-green.	Green.	Greenish-yellow.	Yellow.
Red	Purple	Dark Rose	Light Rose	*White*	Whitish-yellow	Golden-yellow	Orange
Orange	Dark Rose	Light Rose	*White*	Light Yellow	Yellow	Yellow	
Yellow	Light Rose	*White*	Light Green	Light Green	Greenish-yellow		
Greenish-yellow	*White*	Light Green	Light Green	Green			
Green	Light Blue	Sea-blue	Blue-green				
Blue-green	Deep Blue	Sea-blue					
Cyan-blue	Indigo						

5. CIRCLE OF ILLUMINATION.

Size of plate (in inches).	Diameter of circle required to cover the plate (in inches).
3 × 3	4¼ (10,8 cm.)
3¼ × 3¼	4,6 (11,7 cm.)
4 × 3¼ (10 × 8 cm.)	5⅛ (13 cm.)
4¼ × 3¼	5,3 (13,5 cm.)
5 × 4	6,4 (16,3 cm.)
6½ × 4¾	8 (20,3 cm.)
7 × 5	8,6
7,5 × 5	9
8½ × 6½	10,7
10 × 8	12,8
12 × 10	15,6
12 × 15	19,2

6. ANGLE OF VIEW.

Divide the horizontal diameter of the plate by the equivalent focus of the lens, or, for a near object, the conjugate focal distance. Or, if you wish to know the angle of view corresponding to the diagonal of the plate, divide the diagonal of the plate by the equivalent focus of the lens. Then

If the quotient is	The angle is	If the quotient is	The angle is	If the quotient is	The angle is
0,282	16°	0,808	44°	1,4	70°
0,317	18°	0,849	46°	1,45	72°
0,353	20°	0,89	48°	1,5	74°
0,389	22°	0,933	50°	1,56	76°
0,425	24°	0,975	52°	1,62	78°
0,462	26°	1,0	53°	1,678	80°
0,5	28°	1,02	54°	1,729	82°
0,536	30°	1,063	56°	1,8	84°
0,573	32°	1,108	58°	1,865	86°
0,611	34°	1,155	60°	2,0	90°
0,65	36°	1,2	62°	2,182	95°
0,689	38°	1,25	64°	2,38	100°
0,728	40°	1,3	66°	2,856	110°
0,768	42°	1,36	68°	3,464	120°

7. W. E. DEBENHAM'S EXPOSURE TABLE FOR ENLARGEMENTS.

Proportion of image to original (linear).	Distance of image from lens in terms of principal focus.	Proportionate exposures.	Exposures proportioned to that required for copying same size.
$\frac{1}{30}$	$1\frac{1}{30}$	1,07	0,27
$\frac{1}{20}$	$1\frac{1}{20}$	1,10	0,28
$\frac{1}{10}$	$1\frac{1}{10}$	1,21	0,3
$\frac{1}{8}$	$1\frac{1}{8}$	1,27	0,31
$\frac{1}{6}$	$1\frac{1}{6}$	1,36	0,34
$\frac{1}{4}$	$1\frac{1}{4}$	1,56	0,39
$\frac{1}{2}$	$1\frac{1}{2}$	2,25	0,56
$\frac{3}{4}$	$1\frac{3}{4}$	3,06	0,76
(Same size) 1	2	4	1
2	3	9	2,25
3	4	16	4
4	5	25	6,25
5	6	36	9
6	7	49	12
7	8	64	16
8	9	81	20
9	10	100	25
10	11	121	30
11	12	144	36
12	13	169	42
13	14	196	49
14	15	225	56
15	16	256	64
16	17	289	72
17	18	324	81
18	19	361	90
19	20	400	100
20	21	441	110
21	22	484	121
22	23	529	132
23	24	576	144
24	25	625	156
25	26	676	169
26	27	729	182
27	28	784	196
28	29	841	210
29	30	900	225
30	31	961	240

8. TABLE FOR ENLARGEMENTS.

Focus of Lens.	Times of Enlargement and Reduction.							
	1	2	3	4	5	6	7	8
in.	in.	in.	in.	in.	in.	in.	in.	in.
3	6 6	9 4½	12 4	15 3¾	18 3⅗	21 3½	24 $3\frac{3}{7}$	27 3⅜
3½	7 7	10½ 5¼	14 4⅔	17½ 4⅜	21 4⅕	24½ $4\frac{1}{12}$	28 4	31½ $3\frac{15}{16}$
4	8 8	12 6	16 5⅓	20 5	24 4⅘	28 4⅔	32 $4\frac{4}{7}$	36 4½
4½	9 9	13½ 6¾	18 6	22½ 5⅝	27 5⅖	31½ 5¼	36 $5\frac{1}{7}$	40½ $5\frac{1}{16}$
5	10 10	15 7½	20 6⅔	25 6¼	30 6	35 5⅚	40 $5\frac{5}{7}$	45 5⅝
5½	11 11	16½ 8¼	22 7⅓	27½ 6⅞	33 6⅗	38½ $6\frac{5}{12}$	44 $6\frac{2}{7}$	49½ $6\frac{3}{16}$
6	12 12	18 9	24 8	30 7½	36 7⅕	42 7	48 $6\frac{6}{7}$	54 6¾
7	14 14	21 10½	28 9⅓	35 8¾	42 8⅖	49 8⅙	56 8	63 7⅞
8	16 16	24 12	32 10⅔	40 10	48 9⅗	56 9⅓	64 $9\frac{1}{7}$	72 9
9	18 18	27 13½	36 12	45 11¼	54 10⅘	63 10½	72 $10\frac{2}{7}$	81 10⅛
10	20 20	30 15	40 13⅓	50 12½	60 12	70 11⅔	80 $11\frac{3}{7}$	90 11¼
11	22 22	33 16½	44 14⅔	55 13¾	66 13⅕	77 12⅚	88 $12\frac{4}{7}$	99 12⅜
12	24 24	36 18	48 16	60 15	72 14⅖	84 14	96 $13\frac{5}{7}$	108 13½

The first vertical column gives the focus of the lens. The top horizontal row shows the number of times the picture has to be enlarged or reduced. The square where the horizontal row meets the enlargement colours contains the two figures required.

For enlarging, the upper figures in the square give the number of inches the centre of the lens must be removed from the screen or plate; the lower, the distance of the lens from the picture to be copied.

For reducing, reverse the order, *i.e.* the upper figures give the distance of the lens from the picture to be copied; the lower, the distance of the lens from the screen. If the focus of the lens lies between two figures, take the same proportionate interval between the figures in the corresponding squares. Thus, if the lens be 7-in. focus and the negative has to be enlarged three times, place the screen 30 in. and the negative 10 in. from the lens.

9. TABLE OF EXPOSURES (EDER).

Bright sunlight, 10–3, Summer. Type: Ilford or Imperial Special Rapid plate (160 to 180 H. & D.). With a focal plane shutter nearly half the above times may be given.

Proportionate exposure.	Ratio aperture.	Sea and sky.	LANDSCAPES. Open landscape.	LANDSCAPES. Landscape with dense foliage in foreground.	LANDSCAPES. Under trees.		INTERIORS. Bright interiors.		INTERIORS. Dark interiors.		PORTRAITS. Portraits in bright diffused light outdoors.	PORTRAITS. Portraits in good studio light.	PORTRAITS. Portraits in room.	
times.		sec.	sec.	sec.	min.	sec.	min.	sec.	hrs.	min.	sec.	sec.	min.	sec.
1	F/4	$\frac{1}{800}$	$\frac{1}{240}$	$\frac{1}{40}$	—	2	—	2	—	$\frac{1}{2}$	$\frac{1}{24}$	$\frac{3}{16}$	—	$\frac{3}{4}$
2	F/5,6	$\frac{1}{400}$	$\frac{1}{120}$	$\frac{1}{20}$	—	4	—	4	—	1	$\frac{1}{12}$	$\frac{3}{8}$	—	$1\frac{1}{2}$
$2\frac{1}{2}$	F/6,8	$\frac{1}{320}$	$\frac{1}{100}$	$\frac{1}{16}$	—	$4\frac{1}{2}$	—	$4\frac{1}{2}$	—	$1\frac{1}{4}$	$\frac{1}{10}$	$\frac{1}{2}$	—	$1\frac{7}{8}$
4	F/8	$\frac{1}{200}$	$\frac{1}{64}$	$\frac{1}{10}$	—	8	—	8	—	2	$\frac{1}{6}$	$\frac{3}{4}$	—	3
8	F/11,3	$\frac{1}{100}$	$\frac{1}{32}$	$\frac{1}{5}$	—	16	—	16	—	4	$\frac{1}{3}$	$1\frac{1}{2}$	—	6
16	F/16	$\frac{1}{50}$	$\frac{1}{16}$	$\frac{2}{5}$	—	32	—	32	—	8	$\frac{2}{3}$	3	—	12
32	F/22,6	$\frac{1}{25}$	$\frac{1}{8}$	$\frac{4}{5}$	1	4	1	4	—	16	$1\frac{1}{3}$	6	—	24
64	F/32	$\frac{1}{12}$	$\frac{1}{4}$	$1\frac{1}{2}$	2	8	2	8	—	32	$2\frac{2}{3}$	12	—	48
128	F/45	$\frac{1}{6}$	$\frac{1}{2}$	3	4	16	4	16	1	—	5	24	1	36
256	F/64	$\frac{1}{3}$	1	6	8	32	8	32	2	—	10	48	3	12

10. WATKINS' TABLE OF MINIMUM LIGHT FOR SNAPSHOTS.

The numbers give the maximum time his actinometer takes to darken, compatible with a successful exposure.

Plate Speeds.	250	180	130	90	65	45
F/5,6	32	24	16	12	8	6
F/7	24	16	12	8	6	4
F/8	16	12	8	6	4	3
F/10	12	8	6	4	3	2
F/11	8	6	4	3	2	—
F/14	6	4	2	2	—	—

E.g.—With F/8 and Plate 90 a successful snapshot can just be made when the actinometer takes 6 sec. to darken. If considerably more, it will be useless to expose. (WATKINS.)

NOTE.—The "Photographic Exposure Record," of Wellcome (Burroughs, Wellcome & Watts, London), is an admirable guide to exposure, and ought to be in the hands of every amateur, even if he possesses other exposure books, as it contains a vast amount of useful information.

11. SCOTT'S TABLE OF RECIPROCAL VALUES

of the chemically active light for different hours of each half-month of the year.

WINTER MONTHS.

Time, Morning.	January.		February.		March.		Time, Evening.
	1–15	15–31	1–15	15–29	1–15	15–31	
4							8
5							7
6						30	6
7			30	15	14	7	5
8	30	15	10	6	4	3	4
9	10	6	4	4	2	1,8	3
10	5	4	3	1,8	1,8	1,6	2
11	4	3,5	2,5	1,8	1,7	1,5	1
12	3,5	3	2,5	1,8	1,6	1,4	12
	15–31	1–15	15–30	1–15	15–31	1–15	
	December.		November.		October.		

SUMMER MONTHS.

Time, Morning.	April.		May.		June.		Time, Evening.
	1–15	15–30	1–15	15–31	1–15	15–30	
4						30	8
5			30	15	14	10	7
6	15	12	8	6	5	4	6
7	6	4	3	2,5	2,3	2	5
8	2,5	2	1,8	1,7	1,5	1,6	4
9	1,7	1,6	1,5	1,4	1,3	1,3	3
10	1,5	1,4	1,3	1,2	1,1	1,1	2
11	1,3	1,1	1,1	1,1	1·	1	1
12	1,2	1	1	1	1	1	12
	15–30	1–15	15–31	1–15	15–31	1–15	
	September.		August.		July.		

12. TABLE OF DIAPHRAGM VALUES.

Ratio aperture.	U.S. (uniform system of R.P. Society).	Dallmeyer's $1/\sqrt{10}$.	Zeiss' F/50.	Watkins', for calculating with actinometer.
F/3,16	—	1	—	—
F/4	1	1,5	—	—
F/4,5	—	—	128	—
F/5	1½	2,5	—	—
F/5,6	2	3	—	—
F/6,3	—	—	64	—
F/7	3	5	—	—
F/8	4	7,5	—	1
F/9	—	—	32	—
F/10	6	10	—	1¼
F/11	8	15	—	2
F/12,5	—	—	16	—
F/14	12	20	—	3
F/16	16	25	—	4
F/18	—	—	8	—
F/20	24	40	—	6
F/22	32	50	—	8
F/25	—	—	4	—
F/28	48	75	—	12
F/32	64	100	—	16
F/36	—	—	2	—
F/40	96	150	—	24
F/45	128	200	—	32
F/50	—	—	1	—
F/56	192	300	—	48
F/64	256	400	—	64

13. TABLE OF PINHOLE AREAS OF CONFUSION.

Miethe investigated the areas of confusion formed by different-sized pinholes for different camera extensions, and found the following apertures gave the best results (*i.e.* the smallest confusion circles) with the camera extensions given in the table.

Size of pinhole in mm. . .	0,09	0,1	0,2	0,3	0,4	0,5	0,6	0,6 mm.
Length of camera . .	10	20	30	50	100	200	300	400 mm.
Diameter of confusion circle in mm.	0,120	0,140	0,201	0,262	0,369	0,579	0,636	0,748 mm.

14. TABLE OF BEST DIAMETER OF APERTURE FOR PINHOLE CAMERA.

(*The object is supposed to be more than* 15 *ft. away.*)

No. of needle.	Diameter of hole in fractions of an inch.	Distance of plate from pinhole.	Ratio between diameter of hole and distance of plate = F/No.	Exposure necessary. — Minutes for seconds in terms of ratio aperture.
	in. min.	in.		
1	1/22 = 1,14	32	1/700	F/120
2	1/23 = 1,09	28	1/640	F/110
3	1/26 = 1	23	1/600	F/95
4	1/28 = 0,82	20	1/560	F/80
5	1/31 = 0,80	15	1/460	F/75
6	1/34 = 0,24	13	1/440	F/70
7	1/39 = 0,64	10	1/390	F/60
8	1/44 = 0,57	8	1/350	F/56
9	1/49 = 0,51	6	1/290	F/48
10	1/54 = 0,46	5	1/270	F/40

The expanse necessary is given in terms of the ratio aperture, reckoning minutes for seconds. Allowance has been made for the diffraction effect of the aperture.

Thus Needle No. 8, with an 8-in. extension of camera, requires sixty times the exposure of a lens stopped down

to F/56, *i.e.* the same exposure reckoned in minutes which the lens requires in seconds.

Example.—Supposing the exposure, with a lens working at F/8, requires $\frac{1}{60}$ sec., the needle will require $(\frac{56}{8})^2 = 7^2 = $ *49 sec.* If the same lens requires 1 sec. exposure, the pinhole will require 49 min. (The above table is partly derived from Watkins' table.)

15. COMPARATIVE SPEED OF PLATES.

(*Altered and extended from Eder's tables.*)

Degrees Scheiner.	Relative sensitivity.	Intensity of light. Second-meter candles.	Degrees Warnercke. Mean transparency.	Degrees Warnercke. Greatest transparency.	Degrees Hunter and Driffield.	Degrees Watkins.	Degrees Wynne.	Plate.
					½[1]	1	5⅓[2]	Auto-
					1	2	10	chrome.
						3	11	Lantern
					2	4	14	plate.
c	1	1,263	8	11	3,2	—	15	
b	1,27	0,994	9	12	4	6	16	
a	1,62	0,779	10	13	5	—	18	
1	2,07	0,610	11	14	6,5	8	20	
2	2,64	0,475	12	15	8	12	22	Slow plate.
3	3,36	0,376	13	16	10	—	26	
4	4,28	0,293	14	17	13	15	28	
5	5,45	0,232	15	18	16	20	32	
6	6,95	0,183	16	19	20	32	39	
7	8,86	0,143	17	20	26	45	45	
8	11,3	0,112	18	21	32	—	—	Medium.
9	14,4	0,086	19	22	40	—	—	
10	18,3	0,069	20	23	52	60	56	
11	23,4	0,054	21	24	60	90	64	Rapid.
12	29,8	0,042	22	25	80	120	71	
13	37,9	0,033	23	26	100	—	78	
14	48,3	0,026	24	27	130	180	90	Extra
15	61,0	0,021	25	28	160	240	110	
16	78,5	0,016	26	29	200	384	111	rapid.
17	100	0,013	27	30	260	512	128	Lightning
18	—	—	28	31	320	—	—	plate.

[1] According to E. J. Wall, the correct factor should be 0,66.
[2] „ „ „ „ „ „ 6,4.

16. SLOWEST EXPOSURES NECESSARY TO SECURE SHARPNESS.

Conditions.—Focal plane or other highly effective shutter. Lens, 5 to 6½-in. focus. Nearest object, 45 ft.

	sec.		sec.
Ordinary street scenes with traffic. No rapid motion . . .	$\frac{1}{10}$	to	$\frac{1}{25}$
Trees, moving with light breeze	$\frac{1}{50}$	to	$\frac{1}{100}$
,, ,, ,, strong wind	$\frac{1}{200}$	to	$\frac{1}{300}$
Animals grazing: cows, sheep, and horses, $\frac{1}{8}$ sec.; if restless or teased by flies	$\frac{1}{100}$	to	$\frac{1}{200}$
Yachts, motor boats, 10 knots per hour, viewed end on . .			$\frac{1}{30}$
,, ,, ,, ,, ,, broadside on	$\frac{1}{200}$	to	$\frac{1}{250}$
Trains, 30 miles an hour, nearly end on			$\frac{1}{150}$

For trains nearly broadside on, motor-cars, horses galloping, divers, birds on wing, etc., all calculations are useless. You must use quickest shutter, and largest diaphragm compatible with density of negative and sharpness of image (for which see other tables).

17. FACTOR NUMBERS (Watkins').

Developer.	Factor.			Developer.	Factor.		
	Soft.	Normal.	Hard.		Soft.	Normal.	Hard.
Adurol . . .	4	5	6	Ortol	7	10	12
Amidol . . .	7	10	12	Paramidophenol . .	12	16	18
Azol (Johnson)	20	30	35	Pyro-catechin . . .	7	10	12
Diogen . . .	8	12	15	,, (crystoid)	22	30	35
Dionol (Diami-				Pyro-metol	6	9	11
dophenol . .	44	60	75	Pyro-soda without bromide 1 gr.	13	18	22
Edinol . . .	14	20	25	,, ,, 2 ,,	9	12	14
Eikonogen . .	8	12	15	,, ,, 3 ,,	7	10	12
Glycin (soda) .	6	8	10	,, ,, 4 ,,	6	8	10
,, (potash)	9	12	16	,, ,, 5 ,,	5	6½	8
Hydroquinone.	8	4,5	5	Pyro-soda with bro-			
Imogen . . .	4	6	8	mide (halve the			
Kachin . . .	7	10	12	above factors) . .	—	—	—
Kodak powders	13	18	23	Quinomet	22	30	36
Metol. . . .	20	30	35	Rytol (Burroughs,			
Metol-hydro-				Wellcome & Co.) .	10	12	15
quinone . .	10	12	15	Rodinal	30	40	50
Metaquin . .	9	12	14	Synthol	22	30	35

Note.—The factor (at least in the case of Pyro and Amidol) varies inversely with the percentage amount of the active ingredient, and inversely with the amount of restrainer (Bromide, etc.).

The factor governs the contrast thus: For more contrast, use a higher factor; for flat negative, soft contrast, a lower one,

Roughly speaking, for soft contrasts use three-fourths of the normal factor; for strong contrasts, add one-fifth to the normal factor.

Example.—Metol-quinol is used as the developer. The image first appears after 20 sec. Since the factor is 12, the plate must be left in the developer for 20 × 12 sec., *i.e.* 4 min. If soft contrast be desired, the plate must be left in for 20 × 9 sec., and for hard contrasts, for 20 × 15 sec.

Rule for factor developing.—Multiply the number of seconds that have elapsed between pouring on the developer and the first appearance of the image by the factor number. The product gives the time that the plate should remain in the developer.

Double emulsions, such as Cristoid films and Thomas's plates, require at least double the time of the factor. Other plates, whether slow, fast, or isochromatic, do not appear to affect the result.

Rule for combination developers.—If equal quantities of each be used, half the sum of the two factors will be the factor of the mixture. If the mixture contains unequal parts, proceed as follows:—

Let f = factor number of solution A;
f' = factor number of solution B;
x = number of ounces of A;
y = number of ounces of B.

Then the combined factor number

$$F = \frac{fx + f'y}{x + y} \quad . \quad . \quad . \quad . \quad . \qquad [87]$$

Example.—A mixture is made of 4 oz. of hydroquinone and $1\frac{1}{2}$ oz. of metol. What is the combined factor F? The factor of hydroquinone is 5, that of metol is 30, therefore

$$F = \frac{fx + f'y}{x + y} = \frac{4 \times 5 + (1{,}5 \times 30)}{5{,}5} = 12 \text{ (approx.)}.$$

This does not hold strictly true with pyro developers, which affect the speed of other developers in a different way.

As regards the ultimate image, all developers appear to give the same, or nearly the same, result, but the rate at which

the image first appears, as well as the time necessary to acquire a standard density and gradation, differ enormously.

Thus, in the case of rodinal, metol, and dianol (diamidophenol) the image flashes out quickly, but it requires to be developed for a long time in order to acquire sufficient density, while, in the case of strong pyro-soda, adurol, and hydroquinone, the image takes a long time before appearing, but requires a short development to secure the necessary density.

18. INSTRUCTIONS FOR USING AND DEVELOPING THE THAMES COLOUR PLATE.

Filling the dark slide.—Insert a Thames colour screen in dark slide or carrier, film up, *i.e.* in such a manner that the glass side of the screen is, when in the camera, towards the lens. On this place a Thames sensitive plate, film downwards, so that screen and plate are film to film. The plates are packed in twos, film to film, so that there is no cause for doubt as to which is the film side. Place a piece of dead black paper over the whole before closing down slide.

Exposure.—With compensation screen in position, speed of plate about Hurter and Driffield 12.

First developer.—

No. 1.

Hydroquinone	½ oz.
Potass metabisulphite	½ oz.
Water	20 oz.

No. 2.

Caustic potash	1 oz.
Water	20 oz.

Use equal quantities of 1 and 2, and as development is carried on in the dark, it is advisable to take 1½ oz. of the mixed developer for a quarter-plate, and 3 oz. for a half-plate. Develop for three minutes, and wash under tap for a minute. Then, still in the dark, place in a dish containing a 10 per cent. solution of ammonium persulphate, freshly made up, for one minute. This should not be used more than twice.

Reversal.—Then remove and wash for one minute, and place in a bath as follows. This and subsequent operations must not be done in the dark room, but in ordinary light:—

Stock A.

Potass permanganate	36 grains
Water	20 oz.

Stock B.

Sulphuric acid	160 minims
Water	20 oz.

For use, take equal parts. The plate should remain in this until the image just developed entirely disappears, which may be judged by looking at the glass side and noting that all the black has gone. The plate must now be re-developed in the following:—

Re-developer.—

Sulphite of soda	$\frac{1}{4}$ oz.	Stock.
Water	10 oz.	

Should not be kept more than three days.

To 2 oz. of above, add 6 grains of amidol and 2 drachms of a 5 per cent. solution of bromide of potassium. Carry development until, on looking through the positive, it appears sufficiently dense (about four minutes will be found correct), allowing for a little loss of density in the fixing. Wash for $1\frac{1}{2}$ min.

Fixing.—Then fix in hypo, 4 oz.; water, 20 oz. Wash well under tap and put in rack to dry.

Registration.—Place the positives, when dry, on the screen plate, film to film; hold them up, looking through, and fit the registration marks; then temporarily clip with bull-dog clips, and bind up as for lantern slides.

19. INSTRUCTIONS FOR DEVELOPING THE AUTOCHROME PLATES.

Letter of Indication.	Developer.	Time of action.	Remarks.
A	Pyrogallic acid 3 grammes Sulphite of soda } 2 drops Commercial lye } Potassium bromide 2 gr. Water . . . . 100 c.c.	2 to 5 minutes according to appearance of image. Factor number, 6.	Begin development with full quantity of A and ¼ of B, dilute with full amount of water, then add part or whole of remainder of B as image requires.
B	Ammonia ·880 . 10 c.c. Anhydrous sodium sulphite . . . 10 gr. Water to . . . 100 c.c.		
C	Potas. permang. . 0,2 gr. Pure sulphuric ac. 1 c.c. Water . . . . 100 c.c.	3 minutes.	See that crystals are quite dissolved.
D	Sodium sulphite (anhyd.) . . . 1,5 gr. Amidol . . . . 0,5 gr. Water . . . . 100 c.c.	2 to 4 minutes.	Wash well before using D. If image sufficiently strong omit E, F, G, and H.
E	C diluted . . . 1 : 50	10 to 15 seconds.	
F	Pyrogallic acid . 0,3 gr. Citric acid . . . 0,3 gr. Water (distilled) . 100 c.c.	½ to 2 minutes.	Only use if image is weak or dull. Stop when developer gets turbid.
G	Silver nitrate . . 0,5 gr. Water (distilled) . 100 c.c.		
H	Potas. permang. . 0,1 gr. Water . . . . 100 c.c.	½ to 1 minute.	Rarely necessary.
I	Sod. hyposulphite 150 gr. Sod. bisulphite (commercial) . 50 gr. Water . . . 1000 c.c.	2 minutes.	Do not exceed 2½ minutes. Then wash for 5 minutes.

20. METRIC EQUIVALENT TABLES.

Solid measures (Metric).	
1 Milligram	= $\frac{1}{65}$ grain
1 Centigram	= $\frac{1}{6,5}$ = 0,154 grain
1 Decigram	= 1,543 grains
1 Gramme	= 15,43 ,,
2 ,,	= 31 ,,
3 ,,	= 46 ,,
4 ,,	= 62 ,,
5 ,,	= 77 ,,
6 ,,	= 92,5 ,,
7 ,,	= 108 ,,
8 ,,	= 123 ,,
9 ,,	= 139 ,,
10 ,,	= 154 ,,
14 ,,	= 216 = ½ oz. avoir.
20 ,,	= 308 grains
28 ,,	= 437 grains = 1 oz. av.

Solid measures (British).	
1 grain	= 65 milligrams
2 ,,	= 13 centigrams
3 ,,	= 19,5 ,,
4 ,,	= 26 ,,
5 ,,	= 32,4 ,,
6 ,,	= 39 ,,
7 ,,	= 45 ,,
8 ,,	= 52 ,,
9 ,,	= 58 ,,
10 ,,	= 65 ,,
20 ,,	= 1,3 grammes
30 ,,	= 1,95 ,,
40 ,,	= 2,6 ,,
50 ,,	= 3,24 ,,
¼ oz. avoir.	= 7 ,,
½ ,, ,,	= 14,17 ,,
1 ,, ,,	= 28,35 ,,
1 lb. = 16 oz.	= 454 ,,

Fluid measures (Metric).	
1 c.c.	= 17 minims (m.)
2 ,,	= 34 ,,
3 ,,	= 51 ,,
3,5 ,,	= 60 = ʒi (1 drachm)
4 ,,	= 68 minims
5 ,,	= 85 ,,
6 ,,	= 1 dr. 41 m.
7 ,,	= 2 ,,
8 ,,	= 2 ,, 15 ,,
9 ,,	= 2½ ,,
10 ,,	= 2 ,, 49 ,,
15 ,,	= 4 ,, 14 ,,
20 ,,	= 5 ,, 8 ,,
25 ,,	= 7 ,,
28 ,,	= ℥i (1 fl. oz.) = 480 m.
30 ,,	= 8½ dr.
50 ,,	= ℥i ʒvi (1 fl. oz. 6 drms.)
75 ,,	= ℥ii ʒv
100 ,,	= ℥iiis (3½ fl. oz.).
1000 c.c.	= 1 litre = 32,2 fl. oz.

Fluid measures (British).	
1 minim (m.)	= $\frac{1}{17}$ c.c. = 0,06 c.c.
5 ,,	= 0,29 ,,
10 ,,	= 0,59 ,,
20 ,,	= 1,18 ,,
30 ,,	= 1,77 ,,
40 ,,	= 2,36 ,,
50 ,,	= 2,95 ,,
1 drachm (ʒi)	= 60 m. = 3,5 c.c.
2 ,,	= 120 ,, = 7 ,,
2½ ,,	= 9 c.c.
3 ,,	= 10,65 c.c.
4 ,, (½ fl. oz.)	= 14 c.c.
1 fl. oz. (℥i)	= 28 ,,
2 ,, (℥ii)	= 57 ,,
3 ,, (℥iii)	= 85 ,,
3½ ,, (℥iiiss)	= 100 ,,
4 ,, (℥iv)	= 113 ,,
1 pint (Oi)	= 568 ,,
35 fl. oz.	= 1000 c.c. = 1 litre
1 gallon	= 4,546 litres

Measures of Length (Metric).

1 Kilometre = 1000 M. = 1094 yards = $\frac{5}{8}$ mile.
1 Metre (M.) = 10 decimetres = 100 cm. = 39,37 in.
1 Decimetre (dm.) = 10 cm. = 3,937 in.
1 Centimetre (cm.) = 10 mm. = 0,3937 in.
1 Millimetre (mm.) = 1000 microns = $\frac{1}{25}$ in. = 0,03937 in.
1 Micron (μ) = 1000 micromillimetres = $\frac{1}{25000}$ in.
1 Micromillimetre ($\mu\mu$) = 10 Angstrom units = $\frac{1}{1000000}$ mm. = $\frac{1}{25000000}$ in.

Length of	red	light	A	line = 768 $\mu\mu$.
,,	orange	,,	C	,, = 656 ,,
,,	yellow	,,	D	,, = 589 ,,
,,	greenish-blue	,,	F	,, = 486 ,,
,,	deep-blue	,,	G	,, = 431 ,,
,,	violet	,,	H	,, = 397 ,,

Measures of Length (British).

1 mile	= 1609 M.
1 furlong	= 201 M.
1 yard	= 91,41 cm.
1 foot	= 30,47 cm.
1 inch	= 25,4 mm.
1 line	= 2 mm.

Inches to millimetres.

Inches		mm.		cm.
$\frac{1}{16}$	=	1,58	=	0,16
$\frac{1}{8}$	=	3,17	=	0,32
$\frac{1}{4}$	=	6,35	=	0,63
$\frac{3}{8}$	=	9,5	=	0,95
$\frac{1}{2}$	=	12,7	=	1,27
$\frac{5}{8}$	=	15,9	=	1,59
$\frac{3}{4}$	=	19	=	1,9
$\frac{7}{8}$	=	22,2	=	2,2
1	=	25,4	=	2,54
2	=	50,8	=	5,08
3	=	76,2	=	7,6
4	=	101,6	=	10,1
5	=	127	=	12,7
6	=	152	=	15,2
7	=	177	=	17,7
8	=	203	=	20,3
9	=	229	=	22,9
10	=	254	=	25,4
11	=	280	=	28
12	=	304	=	30,4

The above values are correct to $\frac{1}{2}$ mm.

Centimetres to inches.

cm.		inches.
1	=	$\frac{3}{8}$
2	=	$\frac{13}{16}$
3	=	$1\frac{3}{16}$
4	=	$1\frac{9}{16}$
5	=	$1\frac{31}{32}$
6	=	$2\frac{6}{16}$
7	=	$2\frac{3}{4}$
8	=	$3\frac{5}{32}$
9	=	$3\frac{9}{16}$
10	=	$3\frac{15}{16}$
11	=	$4\frac{5}{16}$
12	=	$4\frac{11}{16}$
13	=	$5\frac{1}{8}$
14	=	$5\frac{1}{2}$
15	=	$5\frac{15}{16}$
16	=	$6\frac{5}{16}$
17	=	$6\frac{11}{16}$
18	=	$7\frac{1}{16}$
19	=	$7\frac{1}{2}$
20	=	$7\frac{7}{8}$

The above values are correct to $\frac{1}{32}$ in.

LIST OF ALL THE FIRMS MENTIONED IN THIS WORK, together with their Postal Addresses and Telephone Numbers.

Name of Firm.	Postal Address.	Telegraphic Address and Telephone No.
Adams & Co. . . .	24, Charing Cross Road	Pyro, London. 4931 Gerrard.
Aldis Bros. . . .	13, Old Grange Road, Sparkhill, Birmingham	Optical, Birmingham.
Beck, R. & J. . .	68, Cornhill, E.C.	Objective, London. 5772 Avenue.
Burroughs, Wellcome & Co.	Holborn Viaduct, E.C.	Central, 13,300.
Busch Optical Co. .	35, Charles Street, Hatton Garden	Purello, London. Central, 2563.
Butcher, W. & Sons, Ltd.	Farringdon Avenue, E.C.	England, London. 5995 Holborn.
City Sale and Exchange	90–94, Fleet Street, E.C.	Films, London. 3210a Wall.
Dallmeyer, J. H., Ltd.	25, Newman St., Oxford St., W.	Dallmeyer, London. 5783 Central.
Demaria Frères . .	169, Quai de Valmy, Paris.	
Fallowfield, J. . .	146, Charing Cross Road, W.	4443 Central.
Gaumont Co. . .	5, Sherwood St., Piccadilly Circus	Chronophone, London. Gerrard, 2430.
Goerz, C. P. . . .	1–6, Holborn Circus, E.C.	Photopsia, London. Holborn, 1696.
Hinton & Co.. . .	Bedford Street, Strand, W.	Central, 7931.
Houghtons, Ltd. .	88, High Holborn, E.C.	Holborn, 2500.
Hughes, W. C. & Co.	82, Mortimer Road, N.	Pamphengos, London. North, 1122.
Imperial Dry Plate Co.	Ashford Road, Cricklewood, N.W.	Impeople, London. 720 P.O., Hampstead.
Johnson & Sons, Ltd.	23, Cross St., Finsbury, E.C.	Caustic, London. Central, 14,132.
Kodak, Ltd. . . .	Head Office: 57, Clerkenwell Rd., E.C.	Kodak, London. Holborn, 1345.
Lancaster, J. & Son, Ltd.	275, Broad St., Birmingham	Lankster, Birmghm. Birmghm., 216 Cent.
Lizars, J.	251, High Holborn, W.C.	Camerated, London. 4654 Central.
London Stereoscopic Co., Ltd.	54, Cheapside, E.C., 106, Regent Street, W.	Stereoscopic, London. Bank, 5093.
Lumière, A. & Sons	Montplaisir, Lyon, France	Lumière, Lyon. T. N., 11.
Lumière N. A. Co. .	89, Great Russell St., W.C.	Diamido, London. Gerrard, 3419.
Marion & Co., Ltd..	22, Soho Square, W.	Noiram, London. Gerrard, 1693.
Negretti & Zambra.	38, Holborn Viaduct	Negretti, London. Holborn, 583.

Name of Firm.	Postal Address.	Telegraphic Address and Telephone No.
Newman & Guardia, Ltd.	90, Shaftesbury Avenue, W.	Goniometer, London. Central, 3525.
Newton & Co. . .	3, Fleet Street, E.C.	Central, 13,785.
Perken, Son & Co., Ltd.	99, Hatton Garden	Optimus, London. Central, 4515.
Ross, Ltd.	111, New Bond Street, W.	Rossano, London. Gerrard, 3540.
Rotary Photo Co., Ltd.	12, New Union Street, E.C.	Rotatoria, London. Wall, 1109.
Royal Photographic Society	66, Russell Square, W.C.	Central, 4124.
Sanders & Crowhurst	71, Shaftesbury Avenue	Optogram, London. Gerrard, 4438.
Sanger-Shepherd & Co.	5, Gray's Inn Passage	Sentido, London. Central, 8722.
Sands, Hunter & Co.	37, Bedford Street, Strand, W.C.	Sands, 37, Bedford St. Central, 12,824.
Shew, J. F. & Co. .	88, Newman Street, Oxford Street, W.	Developer, London.
Sinclair, J. A., Ltd.	54, Haymarket, S.W.	Graculum, London. Central, 8788.
Smith, Dr. J. H. & Co.	Wollishofen, Zurich	Dryplate, Zurich. T. N., 484.
Staley, A. E. & Co.	19, Thavies Inn, E.C.	Opsiometer, London. Central, 754.
Steinheil, C. A. & Sons	Munich, Bavaria (London Agents, Staley & Co.).	
Taylor, Taylor & Hobson	Stoughton Street, Leicester	Lenses, Leicester. National, 134.
Tella Camera Co. .	68, High Holborn	Tellurato, London. Central, 2694.
The Thames Colour Plate Co.	254A, High Holborn, W.C.	8785 Central.
Thornton - Pickard, Ltd.	Altrincham, Cheshire	Pickard, Altrincham. T. N., 69.
Tylar, William . .	41, High St., Birmingham	Tylar Sixways, B'ham. Northern, 546, B'ham.
Urban Trading Co. .	48, Rupert Street, W.C.	Central, 3118.
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Watkins Meter Co.	Imperial Mills, Hereford	Watkins, Hereford.
Watson, W. & Sons	313, High Holborn, W.C.	Optics, London.
Wratten & Wainwright	Croydon, Surrey	Wratten, Croydon. Croydon, 572.
Zeiss, Carl . . .	Jena, Germany, 29, Margaret Street, W.	Zeisswerk, Jena. Diactinic, London. Central, 4007.
Zimmermann, A. & M.	9 and 10, St. Mary-at-Hill, E.C.	Poisonable, London. Central, 8163.

ADDENDUM TO PAGE 83

PROFESSOR T. H. BLAKESLEY'S revised definition of the focal length of a lens was received too late for insertion, but is substantially the same as that I have given in italics on page 83. It is as follows:—

The focal length of a lens or lens system may be defined as: (1) *The distance through which an object must be moved in a direction parallel to the axis, in order to change by unity the relation of the linear dimensions of the object to the corresponding linear dimensions of the image*; or, (2) *The distance through which an image must move in a direction parallel to the axis in order to change by unity the relation of the linear dimensions of the image to the corresponding linear dimensions of the object.*

It must be borne in mind that to render (1) exactly true, the object must not be measured from a plane nearer the lens than 2F (object plane of unit magnification), and in like manner, to satisfy (2) the image must not be measured from a plane nearer the lens than the image plane of unit magnification.

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THE END

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